SCHOOL SCIENCE SERIES, NUMBER FOUR*

REPRODUCTION

*For advertisement of other numbers of the series
see page 146

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REPRODUCTION

BY

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PREFACE

In common with the other books of this series, this little volume seeks to meet the needs of two classes of readers. It is intended in the first place as a supplementary reading book for students in elementary biological courses; and, secondly, for those members of the reading public who are interested in a simple, untechnical account of some of the most wonderful of the processes of life.

One-half of life, whether we are thinking of the life of man or of the lower animals, is that devoted to the building up of successful individuals, and to adjusting these suitably to the demands of their surroundings; the other half has to do with perpetuating the species. These are the two great problems of living things. Both are essential to permanence of life at any level. This book does not undertake to discuss the first of these problems. It tries to develop in a continuous way, as the text-book cannot do, the story of how plants and animals produce and care for their children. In this way the student can get a better sense of the progress made from the lower to the higher organisms, a more adequate idea of the evolution and perfection of the methods of reproduction.

Furthermore, it is more and more becoming the conviction of thoughtful students of education that our young people must come to know and appreciate the meanings of these great functions in human life. Most of them also agree that this instruction, wherever it is given, in home or in school, must be related to and imbedded in the larger body of knowledge of which it is a part. It should not be isolated or emphasized in such a way as to heighten sex-consciousness or to produce shock and uneasiness. The treatment in this book is intended to be such that the whole organic story becomes a background by means of

which human reproduction and sex may be enveloped. The human conditions are so interwoven with plant and animal processes that the essential truths may be assimilated incidentally to the school course in the life-sciences and with the minimum of special instruction on the subject, which may easily become hurtful.

The writer is convinced that there is much in the life-sciences that may be made appealing to the general reader. There is no field of science from which come more discoveries of vital interest to human life and thought. No modern progress has brought out more that is wonderful and important than our advances in biology. Many of these relate to reproduction and are touched upon in this essay.

It is a pleasure to acknowledge helpful criticisms and suggestions from Mr. Maximilian Braam of Hughes High School, Cincinnati; and from Dr. John G. Coulter, the editor of the Series. Acknowledgment is also made of the courtesy of the American Book Company in connection with use of the illustrations on pages 3, 12, 18, 26, 28, 30, 38, 39, 50, 72, 76, 102, and 103.

T. W. GALLOWAY.

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REPRODUCTION

CHAPTER ONE.

THE CIRCLE OF LIFE.

1. Why Do We Call It a Circle? If you stop to think of life on the earth as you have seen it year after year, you realize that it changes very little. This is true whether we speak of the life of mankind or of all life of every kind. There is just about so much grass on the lawn, about so many weeds in the fence rows, about so many insects in the air during one year as another. There are just about as many babies and children and young people and middle-aged folks and old people and those who are passing away at one time as at another. Yet we know that all of us are growing older all the time. Life keeps up a procession in the same direction, and yet does not get any place, or at least seems to be continually getting round to the same place. This sounds like a circle, but the term is rather misleading. We know very well that it is not the middle-aged people who themselves come back and start life over again. It is a new generation that continually follows the old. On account of this seeming recovery of life in the face of universal deaths, we call the course of life a circle or cycle. A given individual does not come back to the starting place, but the race is always being renewed by new, young individuals.

2. What Events Compose the Circle? If then we overlook the fact that there is no real circle, let us see what are the principal points in this seeming round of life. You know that all plants and animals come into life very

small and helpless. They go through a time of rapid growth, which in humans we call childhood and youth. After a time they become mature. Then, for a while, in middle-life, they just about hold their own. Gradually they show signs of old age, and decline, and later die. This is true of practically all individuals of every kind of plant and animal. Some of them have very short periods, lasting a few days or weeks. Many plants go through all these stages in a year. Still others require centuries or even thousands of years to pass from the beginning to the end of life.

3. The Beginnings of Life. No one knows anything of the actual beginnings of life on the earth, but we all have seen the young bean seedling coming out of the seed, the young tadpole just out of the egg, the young chicken just hatched, or the young calf or puppy recently born. This is not really the beginning of life for any one of these, because if they had not been living before sprouting or hatching or being born, these things would never have happened to them. For our present purposes, however, this may be taken as the beginning of the individual. In some way there is in this young plant or animal all the possibilities of the adult. If the conditions are right it will go on day by day adjusting itself to these conditions and will come to be pretty much what its parents were.

4. Growth. Growth is increase in size. There may be other changes in connection with growth, but growth is just this and nothing more. Living things grow by taking up water and stretching the old parts, or by taking up foods of various kinds and building up some new parts. Growth seems a rather simple thing. It is, however, very complex, and it is quite different in different living things.

In most higher plants the growth occurs only at certain definite points. The growth is local. The growing points, where the cells use the water and foods and thus grow and form new cells, are usually at the tips of the twigs

and roots and in a thin shell about the plant, beneath the bark. The inner, older parts of the plant become hard and rigid, and lose their power of growing. (See Figure 1.)

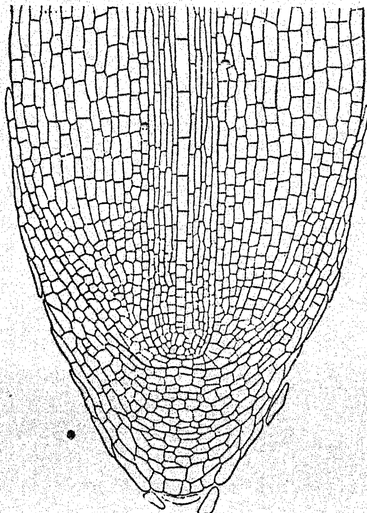

Figure 1. Lengthwise section through a growing root tip of a plant. *From Coulter's Plant Life and Plant Uses.*

It is somewhat different in most animals. They grow as the little pig which "died in clover," that is to say they grow "all over." In them all the cells, with some exceptions, divide and grow. There are no special regions of growth.

With all the differences in growth, however, all growth is alike in that it is due to the fact that some of the cells take in water and foods, and expand. These cells may divide many times and continue to expand after each division.

5. Immaturity. The period of growth comes early in life in those organisms that grow all over. Presently it ceases. In those whose growth is local, it continues throughout life, but it is always in the youngest parts. Growth is thus always a sign of immaturity. During growth the upbuilding processes are more powerful and rapid than the destructive. The length of the growth period in plants and animals differs as much as the length of life itself. These periods correspond in length. If the

whole life period of an animal is long, its immaturity is likely to be long; if the youth is short, the life is likely to be short.

Organisms frequently pass through striking changes in appearance during this period of immaturity. The word **larva** suggests some of these. The immature (larval) butterfly is not like a butterfly, but is a worm-like caterpillar; the immature frog does not look like the adult, but has a tail and gills, as a fish has. The leaves of the seedling plant are very different from those of the old plant. This period is very important in many other organisms beside man. It is the **formative** period. The expression "as the twig is bent the tree inclines," expresses a general law of life. The growth period is the great time of adjustment. It is the period in which the individual gets a chance to make its adjustments to the important conditions of its life. Later, when the individual is full grown, changes or adjustments are made with difficulty, if at all. But in its youth and growth the individual is **plastic;** that is, it can be modified without injury better to fit its environment.

So, in human beings, youth is the time for education, the time of the formation of habits and of character. What you may learn without difficulty now may be much more difficult when you are older. Youth, then, is the great **period of opportunity,** as well as the period of growth. Fortunate indeed is the boy or girl who fully realizes this, and makes the most of youth's rich opportunities before it is too late.

6. Maturity. At maturity a plant or animal comes to its full powers, size, and nature. At this stage the increase is no longer greater than the outgo. They just about balance. The length of time that this is true also varies greatly in different kinds of organisms. Some begin to decline in a few days or weeks after becoming mature. This is true of a great many insects. In others there may

be a mature period of a great many years, as in the various trees or in the larger animals. In man full maturity lasts about fifteen or twenty years; that is, from thirty years of age to forty-five or fifty. These figures are somewhat misleading, inasmuch as some of our qualities may not reach maturity by thirty, and others begin to wane before we reach thirty.

7. Decline and Old Age. We may think that old age is just a matter of time. A little thought, however, will convince you that this is a very small part of the story. A grasshopper or a mouse "grow old" while a child or a colt of the same age is still young. It is not primarily **time** but something **within** which makes old age, and the decline in power that comes with it. In some way the aging plant or animal cannot continue to adjust itself to the conditions about it. This **adjustability to conditions** we find to be the real essence of life. For a while the individual meets fully and profits by the surrounding conditions. It receives stimuli, responds to them, and becomes better because it does this. It learns, so to speak, how, through its experiences, to adjust itself the better. Thus it grows, matures, thrives. After a time, perhaps it loses some of its plasticity or softness, its tissues harden, its habits harden, and it no longer meets all its changing needs so well.

Then, too, it may be that all organisms, and all the cells in the organisms, make poisons in the very act of living, which make it harder to live. For example, if a number of people are shut up in a room, we know that they give off poisons which check and presently stop life. The same is true of many germs that multiply in our bodies and elsewhere. They quite frequently produce substances that make it harder for themselves to live. If this is true of the cells in our bodies, we can see how by a slow wearing out or a slow poisoning each might do its work less and less well, and thus a decline of the whole organism would follow.

Whether this particular explanation is true or not, it is certain that the loss of power, the decline in the work of some of the cells of the body, is responsible for what we call "old age" in the body as a whole.

It is not to be imagined that the external conditions are without influence in this. Aging comes faster under some conditions than under others. All the conditions that help to make life possible have some influence on the rate of maturing and the rate of decline. We find, for example, that human beings tend to mature more rapidly in warm countries. You can "force" plants by increasing the heat and moisture. In general, the conditions that hasten maturity also hasten old age. In human beings many internal conditions and habits also hasten these things. Worry, dissipation, overwork, lack of worth-while work, extreme habits of all sorts seem to increase the rate of living and hasten the moment of decline. It is a paying thing to respect these ways of nature. She does not always hurry, but we can never cheat her in the end.

9. Death. As the decline passes on, and the income becomes less and less able to meet the outgo, the organism loses more and more its power to adjust itself to the outside conditions and to meet its own needs thereby. **Death is merely the entire loss of this power to adapt the internal conditions to the external.** Dying really begins when the decline begins. Death is merely like the final snap of a bar that has been gradually bending toward its breaking point. When the materials, of which the body of a plant or animal is made, have lost their power of adjustment the plant or animal is dead. The very conditions that stimulated and supported its life before now cause the decay of the complex materials.

10. The Cycle. If a body is born, grows into and through youth, matures, grows old and dies, it does not end where it began; except that the matter of which it was made came from the outside world and at death goes back to it.

How then can we say we have a cycle? Merely because somewhere along this course, from the early beginnings to death, **the individual has the power to produce other young individuals.** These are as simple and new as it was at its own beginning. Thus a new start is had, and the cycle is complete. The dying organism does not become young itself; but some time before death it produces others that are young. This is an interesting thing which we are too much disposed to take for granted; the offspring of parents however old are not of the age of the parents, but are young. Why should the product of a parent forty years old be any less than forty years old? Here is the fountain of perpetual youth. It is the only one we are likely to discover; but it is enough. It makes the eternal circle of new individuals, which supplies the materials by which the evolution of the race goes on.

11. Application to Ourselves. This chapter teaches that a fundamental law of life is **adjustment to surroundings.** This sounds rather simple, but it is not as simple as it sounds, especially when applied to human beings. For the things which make up our "surroundings," or **environment** are many and complex, and the question of right adjustment to them is often a question that puzzles the wisest of men.

The **factors** which make up environment we may roughly classify as **natural** and **artificial,** meaning by natural those fundamental facts as to air, water, food, light, weather, etc., to which all men in all times have had to adjust themselves effectively in order to live. By artificial factors, on the other hand, we mean those facts of life which have resulted from the activities of man himself; the things which go to make up what we call civilization. These are factors which change from generation to generation, so that what may have been the right adjustment for our grandparents may not be the right adjustment for us. Chief among these artificial factors are what

we call the "social and economic conditions," and it is in connection with these that the great puzzles of life arise.

Often we see conditions in the relations of men to one another which cause injustice and suffering, and we may, by studying such situations, find that we ourselves by our manner of living are partly responsible for such conditions. Then evidently the thing for us to do is not merely to "adjust ourselves to environment" as environment happens to be, but to seek wisely to alter such features of the man-made environment as cause unjust hardships to others. So we must not take "adjustment to environment" as one simple and sufficient rule of human life, however well it may do for plants and animals. We alone of living things have the powers of reason that have created artificial conditions, and we must constantly use these powers so as to alter these conditions that the best results for all may prevail. Thus we see that the best adjustment to environment on our part may often be an effort to change the environment in some respects, at least in its human or artificial parts.

CHAPTER TWO.

WHAT DO WE MEAN BY REPRODUCTION?

1. The Individual; Its Upbuilding and Fate. In Chapter One you saw the course of life in the individual. This course includes a small start, an increase, a period of maturity, a decline, and in the end death. This is so universal that we come to take it for granted; and we forget to inquire why it is so. We want now to see a little more closely how the individual behaves in this circle.

In most cases the start is more modest than was pictured above. Most individuals really start life as a single cell, which is usually scarcely large enough to be seen with the naked eye. This is true even of some of the very largest plants and animals. We think of the oak as starting in an acorn; but really the acorn is not the beginning. The acorn already contains a young oak. The beginning of the new individual was a single cell back in the tissues of the parent tree. From the fate of this cell it is clear that the power of growth and development must be something marvelous. How can a man or a whale or an oak, with billions of cells and weighing many pounds, come from such small beginnings?

At the bottom of the whole question is the power of the living individual to take up water and other substances, which we call by the general name **foods.** This power you are quite familiar with, even if you do not understand it. The organism so changes foods and combines them as to make new living matter like that of the living object

doing it. Jimmie Jones can take beef and pork, potatoes and pop corn, molasses, butter, and milk, and they soon cease to be these particular things, being changed into Jimmie Jones-stuff. Strangely enough beans will become Jimmie just as much as pork will. He puts his stamp on both, and it isn't quite like the stuff in any other living thing. Indeed, if we were cannibals, as frogs are, and were to eat the flesh of Jimmie Jones, we would have to change it just as much as he does pork and beans before it would be like our own bodies. We could do this. All living things have this power. We call it **assimilation.**

2. The Selfishness of This Process. It is quite clear that this ability to get and use and change other things into one's own substance is a very selfish power. It looks purely to upbuilding the individual. It seeks income rather than outgo. The appetites and longings, which we know as hunger and thirst, exist in order that the individual may be driven to do the work necessary to grow and build up the self. This is the reason that a boy is always hungry. The instincts for taking food are the first and most basal that animals have, because the building up of the self is the very first work they must do. If they do not do this they will never be able to do anything else. We may say that individual selfishness then is the first step in life. While this is true, we have seen that the individual, in spite of this self-care, finally declines and dies.

3. The Outcome of Income. The natural result of assimilation therefore is growth, and then more growth. But naturally organisms cannot very well go on forever growing. There must be some sort of an outgo if any kind of balance is to be kept, such as you actually see in organisms. If Jimmie Jones eats all the time and never gives up anything, Jimmie would become unwieldly; but this is not all. We know from observation that this continued self-building would defeat its own ends. Jimmie

needs exercise, we say, in order to keep well; but exercise is outgo. It destroys some of that which has been built up. You will find, however, that this alternate building up and tearing down results in a better self than the pure self-building. Too much income, without activity, begets softness and stagnant life. Yet in youth the building up must be more rapid than the tearing down. This makes growth.

There is still another way in which this excess which is stored up in youth may be used. Most plants and animals as they approach maturity cease to use the whole of their income for their further growth. Instead, they give off portions of themselves, which finally become entirely separate and form other individuals of the same kind. This is called **reproduction.** It is a kind of growth; but it is growth beyond the limits of the individual. It starts a new individual at the expense of the old. Some of the food which might have gone into the parent goes to build up the new individual. We have found two ways then whereby the individual gets rid of some of its income. These therefore must check its over-growth. They are **activity** and **reproduction.**

4. What Makes an Organism Reproduce? An organism through its whole life has been selfishly laying up in its body the greatest possible amount of material. What could possibly cause it to change its behavior to the very unselfish act of giving a portion of its income, and often a very considerable part of its own body even, to a new individual, whose future will be wholly distinct from it? We have not found a full answer to this question; and yet there are some interesting clues that help us to see how it might have been caused.

In the simplest kind of organism, a single globular cell, all of the nourishment must be absorbed through the outer wall or **surface** of the sphere. On the other hand, the amount of nourishment necessary for it is determined

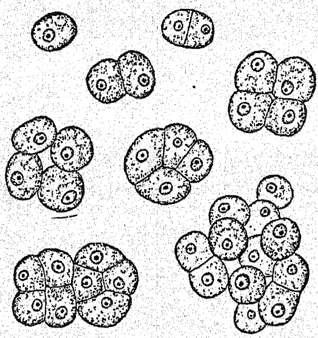

Figure 2. Pleurococcus, a common one-celled plant, as seen under the microscope. —*Coulter's Plant Life and Plant Uses.*

by the **volume** of the same sphere, for the whole volume must be fed. Now as this sphere is nourished and grows, both the surface and the volume increase, **but not at the same rate.** The surface increases as the **square** of the radius; but the volume increases as the **cube** of the radius. For example, if by growing the radius were trebled, the food-taking surface would increase only **nine times;** whereas the mass that is to be fed would be increased **twenty-seven times.** This shows that the living thing must keep up a right adjustment between the internal need and the external supply.

It is important that the student should not fall into an error here. When we ask **why** an organism does thus and so, we may think of either of two things. We are likely to think of the gain or advantage that will come as the result of doing it and assign this as a reason. Now an advantage lies **ahead,** always; and events to come can't act as causes, unless the organism is intelligent and can be thought of as looking ahead. We can see in the case above that division would be advantageous. It would increase the surface without changing the volume, and allow more nutrition and more growth. When we ask **why,** we really mean the **cause** of the thing. The advantage cannot be the cause. The cause must come before the event.

Come back to our example. Not all organisms are as simple as the illustration. Yet **it is true of all organisms**

that the food must be absorbed through surfaces, and it is a volume that is to be nourished. We may say that organisms must stop growing near the point where absorption and nutrition are balanced. It may be, when this condition of balance begins to be felt by a growing organism, that this very condition stimulates it to reproduce. This stimulus would be a real **cause.** In this way the growing power which is lost in the parent is renewed in the offspring, which thus takes onward the torch of life.

5. What is the Meaning of This? Putting together these two processes, upbuilding and reproduction, we have an organism first building itself up in a selfish way through taking in of food and through growth; then, because of this very growth, unselfishly giving a portion of itself to start a new individual life. The student must understand that it is not intended, by the use of the words **selfish** and **unselfish,** that the organisms are conscious of these tendencies or that they have any moral meaning. They relate merely to the fact that one tendency and process builds up the self; the other builds up another individual and does it at the expense of the self. Nutrition tends to make the individual continue; but the individual does not live always by this selfish act. We have seen that it always dies. Reproduction is at the expense of this individual, and frequently results in the immediate destruction of the individual; but it starts a new life and thus perpetuates the species. It is interesting that the selfish act has a **transient** result, while the unselfish act means permanence and continuance of life.

One of the great truths of life then is this: **The best method thus far found in nature to perpetuate life is an alternation of self-building and self-sacrifice, of assimilation and reproduction, of emphasis on the individual and emphasis on the species.** This alternation is found in practically all organisms. It must be a good thing!

6. What is Reproduction? The methods whereby animals and plants reproduce are as widely variable as are any other of the facts of life. The remainder of this little book is given to describing some of these methods. We want here to find what, if any thing, is found in **all** the different kinds of reproduction in the plant and animal kingdoms. We want, in a way, to reduce it to its very lowest terms. Sometimes it is exceedingly simple. Again, it is so covered up and complex that one can scarcely determine the steps. However, reproduction, whether simple or complex, is always this: **the division of an organism into two or more.** This is the fundamental thing. This is always present in reproduction. This **is** reproduction. The other facts that we shall find associated with this one are not reproduction. Division of one organism into two or more is the self-sacrificing act that insures that living things shall not disappear from the earth. The product of these divisions we call **offspring.**

7. Reproduction and the Life-Cycle. The reader will see at once that it is reproduction which makes the cycle. Birth, growth, maturity, decline, and death do not join ends into a cycle. Reproduction is the connection of the passing individual with a new youth. It is the return part of the curve that restores the species to its starting point in spite of the old age and death that overtake the parent.

CHAPTER THREE.

OFFSPRING OF THE SIMPLEST ORGANISMS.

Before we can form any idea of the offspring of the simplest organisms and of the way they come into existence, we must become better acquainted with the organisms themselves.

1. The Simplest Living Things; Their Structures and Powers. In order to understand the nature of these lowest forms of life the student must know something about what the biologist calls a **cell.** The cell is a small unit of the living stuff called **protoplasm.** It commonly has a wall around it. Our bodies and those of all the higher plants and animals are made up of millions of cells. Each unit of living stuff in our bodies has a kind of life of its own, somewhat as a county has its life within the state. Each cell lives its own life, takes up its own food, grows, divides, grows old, and may die. To be sure this is not the whole story. Beside doing its own private work, it does some things in relation with the other cells of the body of which it is a part. It does special work, as secreting or absorbing or contracting or feeling, for the other cells. It has two lives, so to speak: its own individual life, and its part of the life of the whole organism.

Now the simplest animals and plants are something like one of these single, microscopic cells if it were turned loose in nature to live an independent life. These organisms are single cells. They are mostly very minute, though they vary greatly in size. They must have, and

do have, all the powers necessary to sustain individual life, and equally to reproduce and keep the species going. They get food, and use it both to grow and to supply energy. They are sensitive to all the important external conditions of life. They are able to adjust themselves to these conditions.

2. **Where They Are Found.** As one might expect, these minute one-celled plants and animals must live in moist places. Otherwise they would dry up and lose the internal water that is absolutely necessary to active life. Many of them can dry up for days and months and come again into activity when water returns, but, of course, they are not active during this period of dryness. We find them in all waters, both fresh and salt; in the bodies of larger plants and animals, where they may produce diseases; in decaying organic matter, where they assist the decay and live upon the products of it.

They are found in all parts of the world and are among the most interesting of all living things. They are usually transparent under the microscope. Many of them are so small, however, that they can scarcely be seen at all, even by means of our microscopes of highest-powers.

The great improvement of the compound microscope has made these simplest organisms one of the most interesting fields of study in the whole natural realm. You are able to watch all their activities, and even to see them passing through the various stages of their life cycle. Sometimes this cycle is completed in a few hours.

3. **Their Importance in Nature.** Aside from the mere fact that they are interesting to look at and to study, these lowly plants and animals are extremely important to man, and to the other plants and animals that live on the earth. Some of the plants, minute as they are, are green like the leaves of trees. A good example of this is the plant Pleurococcus which you may see as a green stain on the north side of fences and trees. Each plant

is a single cell, but their great numbers make up for their smallness. The green substance in them enables each individual cell to manufacture organic food out of the inorganic materials that come to it.

Other plants, as the **bacteria,** are not green and have not the power of making starches and sugars, but they have other powers equally important. They must get their food chiefly by attacking other plants and animals, either after they are dead or while they are still alive. Those organisms which live at the expense of other living things we call **parasites.**

Finally, we have a great many animals that are one-celled in their structure. These are like the bacteria in not being able to make their own food. They depend on other organisms, living or dead. They are, however, usually much larger than the bacteria and have more striking activities, and rather better development. That is to say, they are more complex.

These lowly things may be very valuable or very hurtful to man and his interests. The simpler green plants may make and store foods, which in turn may be devoured to support more complex organisms. The bacteria and one-celled animals attack dead matter, and by hastening decomposition serve as scavengers. In this way they destroy dead matter and return the elements that compose it back to the earth and air where they may again enter other plants and animals. But for their action, the bodies of the great mass of animals and plants that die every year would remain to vex us for a long time. Within the moist soil itself they are at work tearing down substances, and thus they prepare the way for other life. Bacteria also help to ripen butter and cheese, to make vinegar, to prepare sponges, skins (leather), flax, and some other fabric plants for their commercial uses.

The bacteria also do a good deal of damage to man when they attack foods and other materials that he does

not want to have decay or sour, as milk, fruits, meats, etc.

The greatest harm done to man by these simple plants and animals, however, is in the diseases they produce in the human body or in the animals and plants that we depend on. The most of our contagious and infectious diseases, as tuberculosis, typhoid fever, yellow fever, sleeping sickness, and scores of others are caused by these one-celled organisms and the poisons they produce. Similarly, diseases among hogs, cattle, horses, and poultry; among garden vegetables, orchard fruits, and flowers are caused by them.

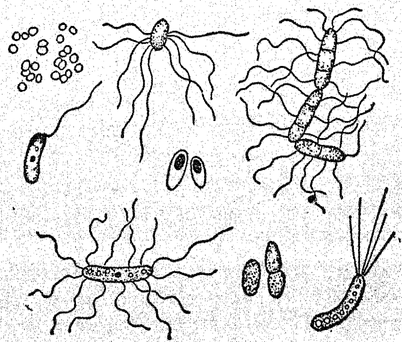

Figure 3. Various types of bacteria, much enlarged. *From Coulter's Plant Life and Plant Uses.*

They do all this damage in spite of the minuteness and small powers of a single organism, simply because they can reproduce so rapidly and effectively.

4. The Method of Their Reproduction. This is often just as simple as can be. When a bacterium grows up to its full size by taking food, it may be a simple globe, or rod, or spiral, depending on the kind. When this has taken place, the cell may at once divide, by a partition through the middle, into two cells, each having one-half the material and one-half the size of the original cell. Each of these daughter cells then grows up to the adult size, and repeats the process. In some bacteria this growth and division may take place in less than an hour. This rapid reproduction is possible because the plant and the process are both so simple. Because of the rapid growth and reproduction it comes about that in

forty-eight hours the descendants of one bacterium, at this rate of one division in an hour, would be two raised to the forty-seventh power.

Most of the one-celled animals and plants have this method of reproducing by simple division into two, though few of them multiply so rapidly as the bacteria.

Some of them vary this method sometimes by dividing the protoplasm of the original cell into several offspring instead of two. In this case each of the offspring gets a correspondingly smaller share of the original body.

5. What of the Parent? This method of reproduction raises an interesting question. The original organism divides into two equal offspring. There is no visible difference between these. There is nothing that would justify us in calling one of them the parent any more than the other. The substance of the parent has gone into them equally. We cannot say that the parent has died in the ordinary sense. There is no corpse; and yet there is no parent. The parent is destroyed completely, as parent, in the act of dividing. The old individual, after being built up, is completely sacrificed in producing two new individuals. They in their turn do the same thing.

Note. There are some other kinds of reproduction found in the one-celled plants and animals. Some of these will be mentioned in other connections, as they will be better understood there. Simple division is found also in some of the higher organisms; but we may fairly say that this simplest of all the methods of reproduction is particularly representative of the simplest organisms.

CHAPTER FOUR.

REPRODUCTION BY BUDS

1. Review. In the lowly plants and animals which were studied in the last chapter the offspring are formed in the simplest possible way, that is, by merely breaking up the parent into two or more equal parts of the original organism. In this process the children do not have to ask, "What shall we do with our parents?" There are no parents left. Many writers have called attention to the fact that in plants and animals of this sort there is no death of the kind we described in an earlier chapter. The parent sacrifices its individual existence, to be sure; but the substance of which it is made seems almost or quite able to renew its youth as it divides, and thus to preserve itself from old age. Of course these organisms may be killed by accident and by unfavorable conditions. Untold millions of them are destroyed by drouth, by cold, and by attacks of other organisms, but probably not from mere old age.

This method of reproduction is called **division** or **fission.**

2. Budding of the Yeast. There is another group of single celled plants, called yeasts, that are important in human industries. They are used in the making of bread, and in brewing beer, and fermenting wines; all this because they have a wonderful power of producing substances that change starches to sugar and break up sugar into alcohol and gases.

These plants are a little larger than the bacteria, but

are still very small and simple. The cells are more plump than the bacteria usually are, varying from elongate to nearly globular. When conditions are good for their life, and one of these cells becomes nearly the mature size, the growing matter within pushes out a little pouch in the wall and some of it flows into this rounded pocket. This is called a **bud**, and it continues to grow, remaining attached to the old cell. Intimate internal communication is kept up between the cells, somewhat like that between a small room and a larger room in the same house.

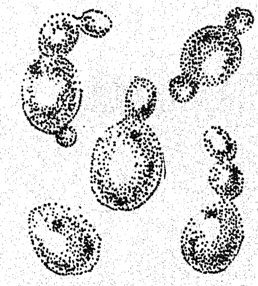

Figure 4. Cells of yeast in various stages of budding

The bud is plainly the beginning of a young cell like the first. As the bud grows larger the connection between it and the mother cell becomes less. In the meantime the first cell may start another bud from another point, or the new cell may itself start a bud. In this way we may get a considerable group of connected cells, some older and some younger. Sooner or later, however, the daughter cells, as they become older, fall apart from the mother cell and thus become independent. How long they remain together and how complex the chains become is determined by the species of yeast and by the food, and the conditions of moisture and temperature in which they are growing.

At other times the yeast cell may divide up the protoplasm on the inside into four small cells, surrounded by the old mother wall. After rest, these finally break loose from the mother cell and live an independent life. Then they grow up to the mature size and begin to reproduce by budding again. This last is not budding. It is more like fission. We shall refer to it again later.

3. The Essential Nature of Budding. It will be seen

from the above that budding is a form of division or reproduction, in which an actual portion of the mother organism forms the beginning. This portion that goes into the young at the start is small, much less than the one-half that goes to the young in division. Much of the nutrition the mother cell takes up after the bud is formed passes on into the young, because of the close connection between the bud and the mother cell. The yeast does not do so much for its bud at the start as is done in fission; but it keeps up its help longer.

This is the simplest form of budding we find. It is, however, a very good picture of the essential nature of it even in the more complex plants and animals in which we find it. Always in buds some of the very structure of the parent organism grows directly into a small, young offshoot or offspring; and a close, nourishing connection remains by which the young grows at the expense of the parent, as a kind of temporary parasite on the parent. Sometimes they separate after a while and live independent lives. In other cases the young remain attached permanently to the old organism until the young themselves are mature and produce other buds. When the whole series of generations remain together permanently like this we call it a **colony.**

4. A More Complex Bud: Hydra. This little fresh-water polyp is found widely in the ponds and lakes of North America and is used very commonly in the laboratory work in zoology. We have in it an animal of many cells as simple as the student is likely to find. It is practically a tube open at one end and closed at the other, the wall of which is two cells thick. Near the open end, the wall is pushed out in a number of hollow tentacles, whose cavities are continuous with the cavity of the animal. When the animal has come about to its mature size and is getting an abundance of food, and the other conditions are right, portions of the body wall may pouch outward with the general cavity of the body

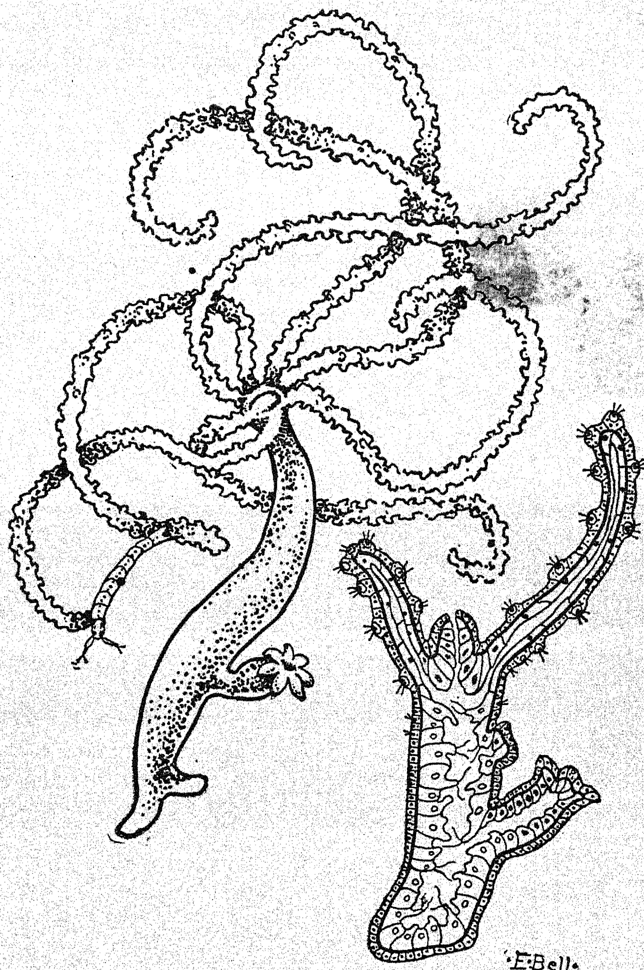

Figure 5. A common form of hydra, much enlarged. The lowermost tentacle has seized the larva of an insect. The lower figure shows the appearance of a young hydra cut through from top to bottom and viewed through a microscope. The mature hydra is usually no more than a quarter-inch in length.

extending into the pouch. This pouch grows and becomes elongated, taking the usual shape of the body of hydra. After a while it produces tentacles at the outer end, a mouth breaks through, and we soon have a young hydra attached to the mother. It has been formed purely by the budding out of the mother. Food may pass into the mouth either of the mother or the bud and finally get to any part of the inner cavity. The bud grows both by the food the mother captures and by that which it captures for itself. It ultimately becomes free and closes up the tube at the point where it was connected with the mother, and depends for a livelihood on its own exertions. One parent may have several buds of different sizes attached to it at once. It may continue to produce buds throughout the season. This condition is not very different from the yeast, except that this is a many celled animal; whereas the yeast is a single cell, and a plant.

In many animals of the group to which the hydra belongs, as in the hydroids and the corals of various kinds, the buds do not separate from the parent stock. By clinging together and by having each its own rate of growth and division, they form most regular, interesting, and varied colonies, which make them look like branching plants. This has given them the name of **zoophytes,** or plant-animals.

5. Buds in Higher Plants. It is in the common plants that the student is most familiar with buds. On almost every plant you have seen buds at the ends of stems, and arising from the sides of stems in the angles of the leaves. These side buds are very much like the buds we have been describing in hydroids, that remain attached to the parent and form complex colonies. In these plant buds there are tissues which are continuous with similar tissues of the parent stem and derived from them. These buds, when they grow, develop more structures, as stems, leaves, flowers, and the like, just like those that are to

be found on the main stem. Furthermore, in a great many plants, if one of these twigs be cut off and be given the proper conditions for life, such a bud or twig is able to form roots and to develop a separate plant just as the young hydra bud does naturally. Such buds then as we see every day in plants may be thought of as a kind of multiplication or reproduction of the essential plant structures. The student can see that this is much more than mere growth as our arms or fingers grow. It is more than the lengthening of a stem after it starts. It is rather as if we could bud out a new arm or leg at a new place, which under proper circumstances would develop all the structures which the body has.

Figure 6. Lengthwise section through a bud of one of the higher plants.

In some of these plants these buds after they are formed may separate from the tree naturally, fall to the ground, and finally grow, take root, and form a new plant. Such are the gemmae of liverworts, the bulblets of ferns, or lilies, and the "sets" of onions.

6. Practical Use of Budding. In horticulture and orcharding we use this quality of the bud to propagate a species. Suppose in some way we find a peculiarly good individual trees of pecans, oranges, apples, peaches, or any one of a great many others. Instead of planting its seeds, we take cuttings consisting of one or more buds from this tree and graft these into healthy scrub stock. The stock is a stem with plenty of roots. If the grafting is properly done, connection will be made with the stock in such a way that its roots will supply the nourishment to the choice cutting. This cutting will keep its quality and not take that of the stock. Ordinarily in grafting

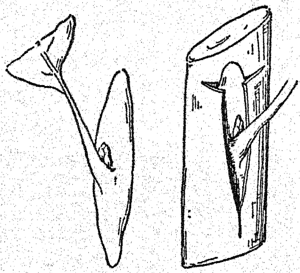

Figure 7. Diagram of the process of budding in the cultivation of peaches. *From Coulter's Plant Life and Plant Uses.*

much of the scrub stem is cut away and the graft is made near the roots. We may, however, graft a bud on any new healthy part of similar kind. Indeed one can graft the buds of many varieties of apple or peach on one stalk, and get as many different kinds of fruits from one tree. Budding and grafting are highly prized methods of artificial reproduction, and they depend upon this natural process of bud formation in the plant, which is itself a kind of reproduction.

CHAPTER FIVE.

REPRODUCTION BY SPORES

1. Another Kind of Division. In budding in yeast you studied a form of division in which the protoplasm of the mother cell pushed the old wall before it. This wall and material became a part of the structure of the new daughters. There is still another way in which the protoplasm of the mother cell makes daughters. In this everything takes place inside the old mother wall. It does not pouch out as in the yeast nor divide into two as in the bacteria. The method is called **internal cell-division.** In such a case we have an ordinary cell, or it may become very much enlarged. At the outset it may have just one nucleus and the usual structures found in a cell. As the cell matures and grows, the nucleus divides into two, these into four, and so on until there are many small nuclei lying in this single mass of protoplasm surrounded by a single cell wall.

Up to this point there may be no trace of any walls in the interior. The nuclei become scattered through the protoplasm. The protoplasm nearest each nucleus rounds off about it. A little later each little ball of protoplasm, containing one of the daughter nuclei, forms a very delicate membrane about itself. We have now many complete though small cells, with walls of their own, inside the old parent cell wall. These small cells are **spores.** As they ripen, the wall of the spore becomes firmer, the old mother wall breaks down, and the spores are thus set free.

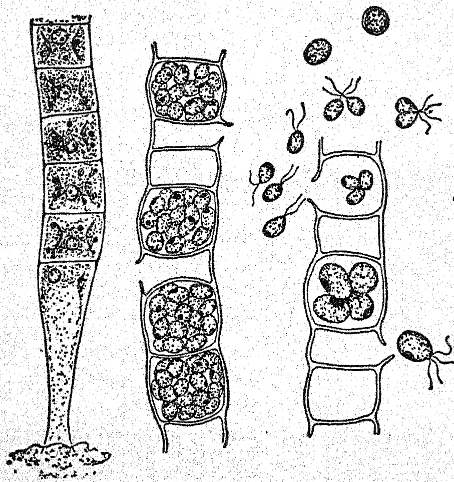

Figure 8. Ulothrix, one of the filamentous algae. The figure at the right shows the production of both spores and gametes by the same individual. *From Coulter's Plant Life and Plant Uses.*

Spores such as are described above are found in many of the algae and fungi.

2. The Nature of the Spore. A spore differs from the small budded daughter cells of the yeast, for example, in this: the spore is merely a reproductive cell. It does not look like the plant from which it came. Furthermore it takes no part in getting its own nutrition, as the yeast bud does. It is nourished by the parent until it is ripe. The yeast bud looks like its parent plant from the beginning, only smaller. Whether spores are formed internally, as described above, or externally, somewhat as yeast buds are formed, they are always just single cells with the power to develop into a plant like the mother. They are not small editions of the plant itself.

3. What of the Original Cell? In the forming of spores the old parental wall is left behind, and sometimes there may be fragments of the old protoplasm that did not enter into any of the spores. These things represent what is left of the parent cell. There is not enough vitality in these remnants to enable the mother cell to continue its

life and to reproduce again. It is destroyed just about as effectively as in fission, in which all the mother substance goes to the daughters.

The advance that is found in this method over simple fission is not in preserving the parent cell and reducing the degree of sacrifice, as was true of budding; but rather it enables one cell in its destruction to produce many young instead of two. This means a much more rapid increase of the species, if only the spores are well enough endowed to carry on the work.

In addition to the advance mentioned above, it often happens that there are other cells of the parent plant left that did not take direct part in making the spores. Such parts may later give rise to more spore-producing cells, and thus the organism may reproduce many times.

4. Many Kinds of Spores. Time would fail us if we should undertake to describe all the different kinds of spores we find among plants. We say "among plants" because animals rarely reproduce by spores. There are a very few lowly animals that produce spores, and they are so lowly that we scarcely know whether to call them plants or animals. On the other hand, practically all plants form spores.

While most spores are formed as described above, inside the old mother cell wall, this is by no means always true. In some cases spores may be merely cells formed by pinching off pieces, so to speak, at the ends of thread-like branches. In these cases they might be thought of as a kind of bud. This is the case in the spores of toad-stools and their close relatives.

The spores of plants are varied in such a way that they meet the needs of the plants in remarkable fashion. They may be formed deep inside certain organs and so need special devices to let them out, such as the active bursting of a capsule; or they may be formed in the air at the very tips of delicate branches, so that the least

disturbance breaks them off and sets them free. The spores of the various molds and fungi that live in the air and on solids are without any power of self motion. On the other hand, most of the spores of the lower algae, which live in water, have **cilia** and can make very definite and interesting motions through the water.

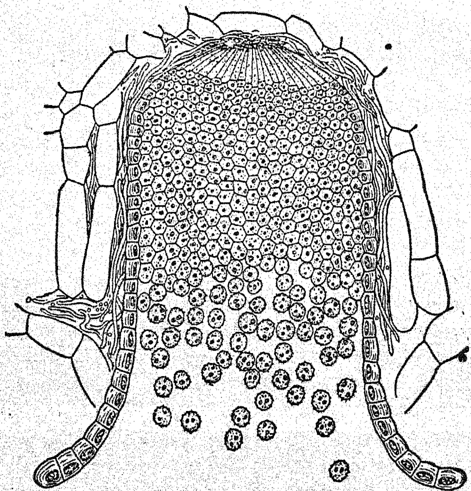

Figure 9. The formation of spores by wheat-rust. This parasite is growing inside a leaf of its host, and is discharging its spores from the under surface of the leaf. *From Coulter's Plant Life and Plant Uses.*

In some plants only one spore may be formed at a place; in others they may run into the thousands. Spores even in the same plant may differ much in size, depending on the way they are formed and the period of development to which they belong.

5. Kinds of Plants That Bear Spores. For a long time the plant kingdom was divided into those plants that reproduce by means of spores, and those that reproduce

by means of seeds. Among the so-called spore-bearing plants we included the algae, the fungi, the liverworts, the mosses, the ferns and their kindred. We now know that the higher plants, that is, those with flowers, also bear spores, and that the flower itself is a spore-producing organ, as well as a seed-producing organ. This will be discussed at more length later.

6. How Spores Behave. They are reproductive bodies looking wholly to the next generation. As compared with other cells in the mother plant the spores are usually highly resistant. Often they float around in the dry air without hurt. Many of them will stand cold much below the freezing point of water. In many of the parent plants these conditions would mean death. On the other hand, the swimming spores are usually remarkably delicate and easily destroyed.

While the spore usually does not have the power of growing in the ordinary way, nor of dividing into two spores as the bacteria divide, it has a definite manner of returning to life and activity. Usually the cell wall around it is a little tough. When conditions are favorable, as for example, after one of these spores has been floating around in the atmosphere and comes into a moist place where its food is abundant, it takes up water and begins to swell. It then sends out through the softened or broken wall a delicate tube of its protoplasm, surrounded by a thin membrane. This tube is the beginning of a new plant. This process by which the spore starts the new plant is called **germination.**

Germination differs very much as to time. In some kinds of spores germination may begin within a few hours after the spore escapes. This is true of the ordinary spores of the bread molds. One may readily see these spores germinate, and begin to form the fine threads of the mold, by placing on an ordinary glass slide a decoction of bread or fruit juice and dusting it with spores. If this is placed in a moist chamber and watched at frequent

intervals during twenty-four or forty-eight hours, the observer will see stages of germination. If conditions are not favorable, the spore may withhold germination for considerable time without hurt. Some other spores will not germinate even under the most favorable conditions until after a period of rest.

Among the fresh water algae, many of which flourish in ponds that are liable to be dried up in late summer and frozen up in the winter, **resting spores** often enable the species to survive these conditions. Drouth would kill the parent plants or the more delicate kinds of spores. Freezing would be likely to do the same. The resting spores, often with thick walls, are unhurt. Furthermore, even though the moisture and temperature are right, the food required by the organism may not be present. In such a case germination would be disastrous, because the young germinating plant is very tender.

We see then that spores reproduce the plant, but they do more than this. Because of their variety in form and in behavior they serve to help adjust the species to some of the unfavorable features in its surroundings and to help it take advantage of the favorable ones.

CHAPTER SIX.

SCATTERING THE SPORES

1. The Problem of Scattering Offspring. Human parents have a way of wanting to keep their children at home and to have them settle near by. But if there are ten children in the family and there are only two hundred acres of land, it is clear that each child must be content with twenty acres or must crowd out some neighbor. Now the problem of these plants that produce so many spores is even more difficult. If all the spores produced by one fungus of almost any kind were to fall right down and germinate on the spot, the crowding would be such that none could thrive. Furthermore, the food at one spot suitable for a given species is always limited. By the time the spores appear the parent plant may have itself exhausted the food. Evidently the species will have a much better chance to keep going if these spores are scattered far and wide. It is sure that most of them will fall at points where they can never succeed, but out of the many there is a chance that some will find favorable places. Wide scattering gives an opportunity to try out the surroundings. Since a single spore cannot try first one locality and then another, as an animal can, this scattering of the offspring is the next best way of getting the members of a species into favorable places.

2. Another Problem. There is another side to this question of scattering. If, for example, there is an injured fish in the water of a pond, and a few spores of the fish

mold should light upon it and germinate and get a footing, we have two distinct problems. One of them, the scattering of the young of the species far and wide, was mentioned in the preceding section. The other grows out of the fact that this fish, before it has completely decayed, can support many plants of the fish mold. Therefore it is a clear gain to the species if this mold has a way whereby it can **quickly** take possession of the fish. The same problem we find in the molds on a culture made of a slice of bread in the laboratory. Both of these classes of organisms have devices for taking full possession of a limited area quickly, as well as devices to extend the species to other spots. In the fish mold, aside from the branching threads of the original parents which spread rapidly over the fish, there are small, short-lived swimming spores that germinate quickly and start new plants near at hand. They are free swimming and might move to considerable distances in the water, but they are attracted by the chemical changes in the water due to the decaying flesh, and so very many of them do not get away from this attractive spot. Thus a very luxuriant growth occurs in a very brief time on the fish. This fact produces the disease and death of many fish, but it means that the mold is being successful.

3. The Effect of the Medium on the Method of Scattering. Plants producing spores grow in air, in water, and in solids, as soil, etc. In the last case, however, it usually happens that the plant sends the spore-bearing branches to the surface, so that the spores are set free either in the air or in water. The problem of scattering the spores must be solved differently in the air and in the water. The water is more heavy and supports the spores better. Furthermore, it keeps them moist, and spores prepared to live in water need not have such thick walls. They may indeed lead a very active life, swimming here and there quite independently of the currents in the water. This is true of many spores of algae and of a few fungi. If they

are not motile and are lighter than water, they may float at the surface and be carried long distances by the currents.

The spores of the majority of the fungi, however, are adapted to the air. They are set free as a dry powdery mass. You doubtless have seen the dense powder arise from a broken puff-ball. This is made up of the thousands of spores which it forms. They have coats which prevent too great loss of their moisture by evaporation, are not actively alive while in the atmosphere, have no motion of their own, and are a little heavier than air, so that in still air they settle to the earth. When the air is in motion, however, they are carried far and wide. They may be dropped temporarily, but unless they fall in a moist place suitable for their germination so that they take hold on the solids, they are readily picked up again and carried on. It is perfectly safe to say that spores may be carried hundreds of miles in times of high winds.

4. The Special Methods of Scattering Spores. The following classification of the methods by which spores are scattered will enable the student to see the variety. Some of these methods are more effective than others, but the sum of all is to make plants very widely distributed.

A. Spores carried by the air.
  1. Without any aid from the plant itself, such as a projection of the spores into the air by some explosive act.
  2. Spores driven to some distance from the parent plant by the presence of some explosive change in the plant itself.

B. Spores carried by water.
  1. Spores are passively carried by currents of water.
  2. In addition to the water currents, some spores have a power of motion of their own.

C. Spores carried by various special moving objects.

1. By adhering to seeds of plants that are carried by wind, water, etc.
2. Carried by insects, birds, and in less degree by other animals.
3. Carried by man in his commerce, agricultural operations, and the other artificial transportation of materials from one part of the country to another.

5. Air-Borne Spores. Spores to be best adapted to being scattered in this way must be freed in a dry, powdery form. They may be carried singly or in loose masses. That they are so carried is readily shown by exposing culture plates to the air, and later placing these in conditions favorably for germination. This proves that there are plenty of such spores being carried by the air. Often a number of species may be discovered on one plate. Great numbers of spores are necessary to make this an effective way to spread a species. The chances are very much against the success of any particular spore. They are produced in unthinkable numbers. Cobb estimates that as many as 500,000,000 spores may be produced from a single head of smutted oats. It is said that the giant puff-ball produces as high as 7,000,000,000,000 spores. Of course nobody ever counted these. A certain small mass is counted under a microscope and the whole mass estimated from this.

Many plants bearing spores have some elastic tissues that cause an explosion when the spores are ripe. In this way they puff the spores into the atmosphere. Here they are much more sure to be picked up and carried away by the wind, since most such plants grow within or upon the surface of the earth or of other solids.

6. Spores Scattered by Water. Reference has already been made to the free-swimming spores of the water molds and algae, and to the carrying of spores by running

water. Water is absolutely necessary for the first kind. Some swimming spores are known to find their way from plant to plant through the water in the soil itself, especially soon after rain or heavy dew. This is true of the fungus causing the "damping-off" of seedlings. Many parasitic plants that attack seed plants exude their spores in moist weather, and rains wash them down from the leaves and bark. Thus they are carried to new parts of the same plant, or to other plants, by first infecting the soil about them.

7. Spores Carried by Insects, Birds, etc. A number of fungi attack fruits, seeds, leaves, and other parts of plants. Insects and birds may use these for foods. These animals carry spores of these fungi from an infected to an uninfected plant, very much as they carry pollen from flower to flower. The spores adhere to the feet and to the mouth parts particularly, and these are the parts most likely to bring them in contact with fresh surfaces. Furthermore, insects may feed directly on the fungi and necessarily carry away spores and distribute them widely.

8. Spores Disseminated by Man. Man, in his mastery of the earth and in his exchange of its products, is sure to distribute spores. Soil spores are carried far and wide by plowing and harrowing, by tools and wheels of vehicles, and by the transportation of soils and manures. The shipment of infected nursery stock, seeds, and fruits is responsible for the wide distribution of the spores of many fungi that attack plants. Similarly, the shipping of hay, grain, vegetables, and any of the raw food products tends to spread any spores that are on these plants. Certain kinds of fungi have thus followed man very closely in his movements around the earth.

CHAPTER SEVEN.

SOME SPECIAL KINDS OF MULTIPLICATION.

1. General. There are some special methods whereby organisms multiply themselves, which are rather common but do not exactly fall under any of the heads discussed above. In some respects they may be thought of as forms of budding, but they are not exactly so. They occur in so many different plants and in so many different ways that it seems desirable to describe them separately.

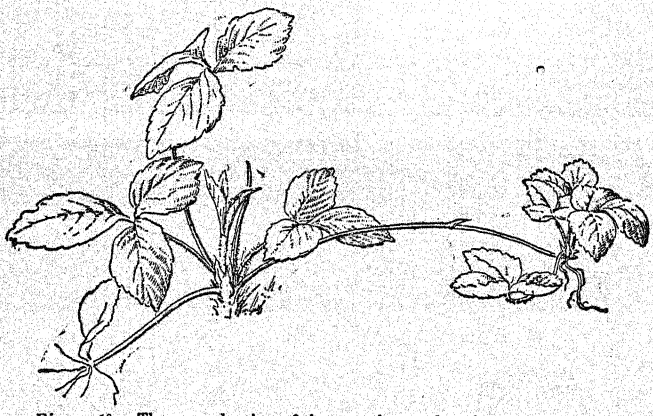

Figure 10. The reproduction of the strawberry plant by runners. *From Coulter's Plant Life and Plant Uses.*

2. Reproduction by Runners. (Stolons). Suppose you have put out a good healthy strawberry plant. As soon

as it gets a good start the next summer, it will begin to send out some branches from near the point where the leaves and roots come together. These will run along the ground instead of growing straight up. At a distance of several inches from the plant, this runner will put out small roots from its lower side, and leaves will grow from the upper side. These soon take the form of a small strawberry plant, connected with the original one. Several of these young plants may start up in a similar way around the parent. For a considerable time these young plants remain connected with the old plant by the runners, but the runners may gradually die as the new plants get roots and leaves enough to support full growth. In time these daughter plants repeat the process.

An exactly similar thing takes place in one of the molds that we often find on our cultures of bread and similar substances. The spores are borne on branches that grow up into the air, but other branches grow along the surface of the bread, and at the end send root-like processes down into the bread and spore-bearing branches up into the air. In other words, a new plant is produced.

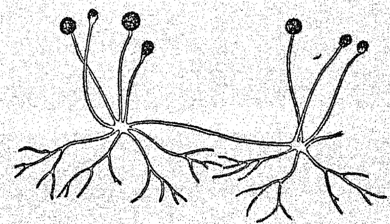

Figure 11. Reproduction of bread mold by spores and by horizontal branches. *From Coulter's Plant Life and Plant Uses.*

The runners just described occur at the surface of the soil or the substance over which it is growing. In many plants, such as some of the grasses and canes, the runner passes along beneath the soil, and here and there sends up a new stalk. These may branch underground and thus produce a great number of new plants from one.

3. Stolons among Animals. The wonderful animal

group of **hydroids,** some of whose members illustrate budding, also contains forms which send out from the parent special tissues that grow over and attach to the solid support, often very tightly. This serves to hold the animal fast, but this is not all. From this tissue may grow up at various distances, depending on the species, and probably on the nutrition and other conditions of life, new hydroids like the parent. Several other groups of animals somewhat less known have very similar habits. In buds proper there is an actual outgrowing of the body tissues into the bud; in this case the bud, if it is to be called so, arises from the attaching tissue rather than from the body itself.

4. The Value of Stolons. There is more meaning in this stolon-forming habit than mere multiplication. It is a special method whereby a plant or an animal that has once got hold in a locality that furnishes abundant food for its rapid growth can rapidly take possession of nearby territory, and can spread out more rapidly than if it depended on seeds and spores. This method acts somewhat automatically to adjust the organism to favorable conditions. If the place is not favorable, the parent plant will not have energy to form runners, but will at once produce spores or seeds which may be carried from the spot to a more favorable one. If it is favorable, there will be energy enough for both methods of reproduction, and the organism will take intense possession of the nearby territory as well as scatter spores. Spores lead to wide spreading; runners lead to full possession of a locality.

5. Tubers. Tubers such as we find in Irish potatoes present a very interesting phase of reproduction. Irish potatoes have seeds and may be propagated by these; but in our cultivation of the potato we do not use this method. From the old plant some stems, **not roots,** arise and grow under ground instead of coming out as others

do. These may grow several inches long in loose soil. At their tips collects food that has been manufactured up in the leaves. This causes them to enlarge at the tip and to form the tuber which we imagine belongs to us rather than to the plant. This potato tuber, as every one knows, has "eyes." The eye is merely a bud, and from each one of these eyes a new potato plant may grow. In practise, we cut the potato in pieces and plant the pieces in trenches prepared for them in order to get new plants next year. In nature, the mother plant dies and these potatoes are left free in the soil, already "planted." They are not "seed," although we do call them "seed-potatoes." The next spring, when suitable growing weather comes, one or more eyes in each of these will send up a new potato plant.

There are many plants, especially early spring plants, that store up food in one or several underground bodies, and then die down. This allows multiplication, but in addition it puts the plant's substance beneath the soil where it may better endure the drouth of late summer and the cold of winter. Also, a new mature plant can spring from these underground stores of food much more quickly than from a small seed. Thus, like the stolon, it is a way of getting quick action. The tulip affords a familiar example of this habit. Among wild flowers, spring beauty, dutchman's breeches, and jack-in-the-pulpit also have this habit.

6. Reproduction by Leaves. Leaves, with their delicate tender structure, would not seem adapted to reproduction. Yet there are certain fleshy leaves which fall to the ground, and, if moisture is sufficient, they will begin to grow roots from the under side and to send up a little stem from the upper side. In a few plants, as some begonias, one can get a new plant by using a leaf instead of a twig as a cutting. A very attractive little fern is known as the "walking fern" from a surprising habit it

has. It has a simple leaf which runs on into a very tapering, drooping point at its free end. Where this touches the moist ground the tip takes root and a new fern starts. This serves the same purpose as was described for runners.

6. Division in Many-Celled Organisms. In an earlier chapter we saw how simple plants, such as bacteria, and simple animals, as protozoa, divide into two. It is more difficult to see how a complex animal with special organs, such as mouth, digestive tract, heart, brain, kidneys, and so forth, could possibly divide. Yet this very thing happens quite commonly in animals of the grade of earthworms. It is not true of the earthworm itself, but it is true of other members of the same division of the animal kingdom.

In worms the division is across the body. Since the mouth, brain, eyes, and other special organs are at the anterior end, these structures must be repeated about halfway back for what is to be the posterior worm. The same is true of the structures that occur at the posterior end. The anterior worm must have a set of these made for him. Of course these new tail structures must lie in front of the new head structures of the rear worm. All these organs usually develop before the two worms separate. We sometimes see four or more such worms in a row, not yet separated, all developed from one worm and soon to break apart.

In some other types of organisms, as in some of the hydroids, the division is said to be lengthwise. In this case the mouth would be split in two, as would all other such organs. In this way each daughter animal gets one-half of each of the original general organs.

7. Regeneration of Lost Parts. If a boy cuts a small piece out of his finger, we fully expect the wound to heal. A scar may be formed, but the space is largely filled up and the skin grows over all. This happens so regularly

that we do not stop to realize its meaning. It means that lost parts can be regrown. Now we humans could not grow a new arm or even a new finger. We do not have much power of regenerating lost structures, but we have enough to heal wounds.

If a lizard loses its tail, it is said that it does in some degree grow again. In crayfishes, if antennae or other appendages be lost, new ones may grow out. This suggests that this power is seen to better advantage in the lower than in the higher animals. It is even more true in animals still lower. In the earthworm it has been shown that the head, brain, mouth and all necessary anterior organs may be cut away. If this is done some six or eight segments back of the head, all these lost organs will be formed again in front of the cut. Similarly, new posterior organs will be regenerated if posterior segments are removed.

In hydra, which is one of the very simplest of the many-celled animals, it is said that any length of the body anywhere may be able to regenerate all the lost parts.

CHAPTER EIGHT.

RELATIONS OF PARENTS AND OFFSPRING

1. Parental Sacrifice. In all these kinds of reproduction you have studied you see that to form the offspring is a drain on the parent. A part of the parent's body goes directly to form each of the young, or some special growth takes place from the parent which forms the young, and in doing so uses up food materials that might have gone to strengthen the parent instead. **This sacrifice is the one unvarying fact in all the varying methods of reproduction.**

2. The Species and the Individual. In such plants and animals as we have been studying, all that an individual can do for the species is to reproduce offspring. This is the very simplest and easiest form in which to introduce individual sacrifice for the race. The species flourishes in proportion as individuals first build themselves up, and then reverse matters and exhaust themselves in putting offspring on the way to success.

3. The Degrees of the Sacrifice. While all plants and animals seem driven by their nature to make this sacrifice, there seems to be a distinct tendency, as we go up the scale, to make the sacrifice as light as possible and still do the work. At least we find it very much lighter in some organisms than in others. For example, we saw in the bacteria and some other simple forms that the parent was at once completely destroyed in forming the two offspring. In the yeast, on the contrary, the new cells

bud off from the old and the parent continues its own life alongside the new offspring. Two offspring cost much less of the body of the yeast parent than of bacteria. In the case of spores, the sacrifice is still less. Only a small part of the parent enters into them.

4. The Size and Number of Offspring. In the bacteria the two offspring are each just one-half the size of the parent. The same is true of all other forms that reproduce by simple division, as some worms. This is an expensive method. Only two offspring are formed in these cases and the parent is entirely destroyed. In the case of the yeast, the parent produces much smaller offspring to start with and then allows it to grow up to standard size. This is even more true in the forms that produce spores. Many of these may produce thousands of spores which are only a minute fraction of the size of the parent plant. The parent may be completely used up in this process or may use a part of its energies, leaving some of its strength for reproduction some other time.

5 How the Problem is Solved. It may help you to understand what happens in different organisms if you see what possible solutions there are. In reproducing, parents

1. May be completely destroyed:
   (a) By producing two offspring, each one-half the size of the parent, as in the bacteria and other forms that simply divide.
   (b) By producing several or many minute offspring, as in some cases of reproduction by spores.
2. May not use up all their substance in reproduction:
   (a) Producing a few young, but much smaller than one-half the parent when first produced. Such are the budded cells in yeast or the young strawberry plants formed by runners. Here the offspring is of new substance made by the parent rather than the old substance of the plant itself.

(b) Producing a large number of minute young in particular portions of the body. Not all the parent is used up. This is the case in many plants.

It should be remembered that many organisms which are not actually destroyed outright by the formation of their young are still so exhausted by producing and maturing them that they die, and do not reproduce again. All our annual herbs would fall in this class. The same is true of some animals, as the salmon, which is often so exhausted by reproducing that death follows.

6. The Problems Related to the Size and Number of the Offspring. We know that in the long run an animal or plant needs to bring only one of its offspring to complete maturity during its own life in order to leave the species as well represented as before. But there are many disasters between the young and their maturity. Therefore very many more must be produced than will ever come to maturity. This is true of all organisms. If all the offspring that any species can produce were to live and mature and produce indefinitely, that species, in a few years, would become a pest. Many must be produced in order to insure one.

Now the advantage in having offspring like the bacteria, one-half grown at birth, is very clear. It only takes a little time for it to become adult, and the dangers that it will not do so are less than if it were one-thousandth part of the adult. On the other hand, the parent is completely destroyed and we have only two of the half-grown offspring instead of the one adult. The advantage of a form that produces thousands of small offspring is that there is more chance of one in a thousand surviving than of one in two, and beside they can be scattered over a wider territory and this increases their chances. On the other hand, these small young have much further to go in developing and the chances of disaster

are correspondingly increased. It is more expensive to produce large offspring, but they are nearer their goal. With a given outlay many more of the small offspring can be produced, but they are not so sure. Each method has its advantages.

7. The Tendency to Diminish the Size of Offspring. As we come up in the plant and animal kingdoms, we find that the size of that part of the parent which enters into each of the offspring is decreased. We find further that less and less of the substance of the parent is given up to making offspring, and that more of the parental body is left to live and reproduce again and again through a considerable period. Thus, instead of parents dying in producing the offspring, the parents may live along side by side with them for a considerable period. By this means the parent may produce even more offspring than if it gave all its substance to offspring at the outset; and it may distribute them through a better period of time.

8. Combination of Methods in One Parent. There are some organisms that use several methods of reproduction. As we have seen, one of the molds produces many small spores, and at the same time, or a little later, it sends out a stolon or two and thus starts a new plant as vigorous as the first. By the first method it gets the advantage of numbers and distribution; by the second it gets more quickly matured offspring, but not so many of them. This combination is a most successful one to insure the adjustment of the plant to its conditions of living. It is found in many plants and animals.

CHAPTER NINE.

CONJUGATION.

1. Review. Let us bring together the kinds of reproduction we have studied thus far. In some forms we have seen the whole parent divide into **two** offspring, each one-half as large as the original parent. In others we have seen the whole parent divide into **many,** small spore-like offspring. Yet others put forth smaller bodies which grow into new individuals without exhausting the mother organism. Still others have special organs in which many minute, single-celled spores are produced and from which the spores escape without the destruction of the parent.

In many of these cases the offspring begin at once to grow into the adult. Some of them, however, may rest days or months before they begin to develop. All of them have the power to develop directly without any special stimulation other than from heat, moisture, food, and so forth.

2. Offspring That May Unite. We have purposely omitted description of an interesting thing that sometimes takes place even in many of the plants and animals mentioned above, side by side with what we have already described. In some of the fresh water algae (as Ulothrix, a simple filamentous plant) the contents of the cells under certain conditions divide into many motile spore-like bodies. Some of these may swim around for a while and then settle down and germinate into the filamentous form

which becomes adult. Some of them, smaller ones, behave with a surprising difference. Instead of germinating, these latter swim a while and then **unite in pairs,** completely fusing the two small offspring into one, which is twice as large as either. After uniting, this resulting cell germinates and produces a new plant very much as the swimming spores do. Here we find two methods in one plant, somewhat similar and yet with a most important difference. (See the figure on page 28.)

This difference is so important and plays such a part in the reproduction of all higher forms that we must examine it more carefully. The new point is that **offspring, instead of developing, unite by twos.** This union is not reproduction, although it starts the development of a new plant. Instead it is just the opposite of reproduction. The plant **reproduced** when the divisions occurred that formed the swimming spores. When these unite in pairs there are only half as many individuals as before the unions. There has been decrease instead of increase.

The individuals resulting from the union of the two cells are more vigorous and more capable of development than either of the cells was before the union. The union has a value in connection with reproduction; but it is not reproduction.

3. Gametes. Single-celled offspring thus may have either of two fates: (1) they may develop without union of any sort, in which case we call them spores; or (2) they may unite by twos to form a body that develops with especial vigor. In this case we call them **gametes,** which means mates or uniting bodies. You will see that this new united body is formed very differently from the way in which spores are formed. The union probably means something in strength and vitality for the next generation.

In the illustration above, all the gametes are of the same size and form. No one could in any way tell them apart. Such union of similar cells we call **conjugation.**

4. Spirogyra. Of the thread-like green algae that we find in our ponds this is one of the most beautiful. The pupil should see it under the microscope, if possible. It is a chain of elongated cells joined end to end. The green matter **(chlorophyll)** is arranged in one or more strikingly regular spiral bands. This is a perfect cell with nucleus, protoplasm, and all the cell organs. As in cells generally, these have been formed by the division of mother cells. The whole filament of cells came by division from one cell. When the right time comes, two filaments that are lying side by side send out from their various cells short branches. Each of these branches grows and unites with a branch from the nearest cell in the other filament. When they meet, the partition dissolves at the point of union, and the cavities of the two cells are thus put into communication. A little later the protoplasm of one of these cells flows through this

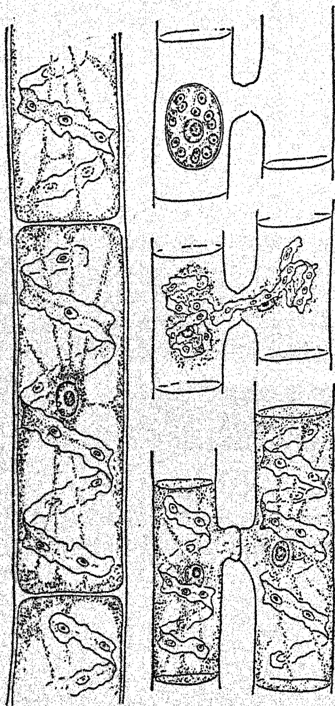

Figure 12. Spirogyra as viewed under the microscope. The figures at the right show the process of conjugation. *From Coulter's Plant Life and Plant Uses.*

little tunnel into the other cell. In this cell the two masses fuse as completely as the gametes of Ulothrix did. The new body, made up of the protoplasm and nuclei of the cells, forms a wall about itself inside the wall of the mother cell.

In the meantime the other cells of the two filaments have been doing the same thing. Thus a row of bodies may be found in one of the mating filaments, while the other filament will be just a row of empty cells. This is conjugation also. Later each of these united bodies germinates and begins a new filament, which again increases by division.

5. Paramecium. This extremely active little animal is so abundant and so transparent that it is very satisfactory for students to study with the microscope. It reproduces by fission, much as the bacteria do. But it frequently varies this by another performance no less interesting. Ordinarily paramecia swim about without paying much attention to each other. At certain times, however, owing to causes we know very little about, they begin to unite in pairs. They do not fuse into one, as other cells we have studied in this chapter. They bring their mouths together, and for a considerable time swim round side by side as one animal. While they are together thus the nucleus in each divides, and a part of the nucleus of each paramecium passes into the other by way of the mouth. This incoming nucleus in each case unites with the part of the nucleus of the other which it finds remaining. Each

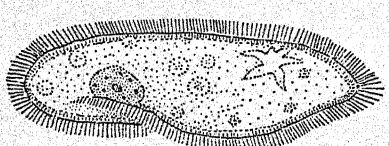

Figure 13. Paramecium, one of the protozoa, magnified. This is a common, one-celled animal, abundant in stagnant water. It reproduces rapidly by division of the whole body into two offspring. Occasionally fusion of two individuals occurs. Paramecium moves actively by means of the lashing movements of its cilia, indicated in the drawing by the fringe of lines.

animal now has part of its own nucleus and part of that of another animal. After this the animals separate. This differs in several respects from the other conjugations described above. The union of the animals is temporary. Each, however, contributes a portion of its nucleus permanently to the other. The number of individuals is not diminished as in other cases we have described. There has just been a change in the inner substance of each animal. After a union of this sort the paramecium has a period of reproduction by fission.

6. **Must These Unions Occur?** In some cases it appears clear that the unions, while common, are not absolutely necessary. Often, even in forms that normally unite, the gametes may develop at once without union. Taking the animal and plant kingdom as a whole, however, the gametes do not find it easy to develop freely into the adult organism without conjugating. In some types the union seems to be absolutely necessary.

7. **What is the Value of the Union?** What possible reason or value these unions have is one of the most interesting questions in biology. We know that they must have some meaning in life because they are so nearly universal. We are not perfectly sure just what the advantage is, but in some way it is prophetic; it looks to the quality of the future generations. It is pretty well established that the stock formed by uniting two cells from different strains is better, generally speaking, than that formed from a single strain. It seems to have more continuous vigor and more variety of development. It appears that the plant or animal, which results from the union of two cells, is less liable to be just like either parent than one resulting from a single parent only. The uniting cells seem to stimulate one another, and, perhaps, to produce a kind of renewal of youth.

CHAPTER TEN

EGGS AND SPERMS.

1. Conjugation the Starting Point. There have been no differences in the gametes or mating bodies in those species we have studied. The ciliated gametes of Ulothrix are of the same size and structure. The mating cells of Spirogyra are apparently alike. The paramecia that unite are as nearly alike as it is possible for organisms to be. Indeed, we call the process conjugation only when the gametes are alike, so far as we can perceive. This condition must be looked upon as the simplest kind of union of offspring. It seems to be the beginning of a process which is very common in both plants and animals. This we must now study.

2. Beginning of Differences in Gametes. Pandorina is a simple green plant made up, when mature, of sixteen cells held together by a jelly which they have secreted. It is not a plant you are likely to see, but it is described in both botanies and zoologies, because it is hard to say whether it is more like plants or animals. It starts as a single cell. By a series of divisions the mature colony of sixteen cells is finally formed. Any one of these sixteen cells may start a new colony by dividing again. Or, instead of this, any one or all of these cells may divide into a number of gametes, which are small and ciliated. These escape from the jelly into the water and unite in pairs. The gametes are almost alike, but differ more or less in size. A smaller and a larger unite.

In Eudorina, which is very much like Pandorina, there is much more difference in the size of the two kinds of gametes. Some of the gametes are quite large and plump. Others are small and spindle-shaped. The differences are at once recognized under the microscope. One of the thin cells unites with one of the plump ones. A small one never unites with a small one, or a large one with another large one. The result is the same as in conjugation. But we call the process **fertilization** when one gamete is much larger than the other. The small gamete is said to fertilize the large one. This name expresses an early guess as to the value which this union has. It suggests that the small cell **stimulates** or **nourishes** the large one for a better development. But we now have good reason to think that the relation is a somewhat deeper one. Each gamete makes **a definite contribution to the individual which results from the combination.**

3. Ovum and Sperm. What has just been described is the beginning of the differences which we find in the offspring (gametes) of all the higher plants and animals. The larger of the gametes is an **egg**, the smaller is a **sperm**, and it may be very small indeed as compared with the egg. The difficulty now is not to tell them apart, but to find anything in which they are alike. In appearance they differ about as much as cells can. Both, however, are single cells. In the egg there is a large amount of nourishment stored by the parent. On the other hand, the sperm is a cell with little more to it than a nucleus. It carries no nourishment, but is usually exceedingly active. All the higher plants and animals produce these two kinds of cells.

4. Eggs and Their Characteristics. An egg, as we have seen, is a cell. It may have some very peculiar structures and powers, but it must always be remembered as a cell. The shell and the white of a hen's egg are not parts of the egg in this sense. Scientifically speaking, the yolk is the

egg proper, while the shell and the white are merely protecting and nourishing structures about it. The yolk is a single very large cell.

Eggs usually have large nuclei, and a good supply of protoplasm. They are without power of motion. They vary in size from that of the ostrich down until they are too small to be seen with the naked eye. There is little connection between the size of the animal or plant and the size of the egg it produces. The eggs of humming birds are many hundred times as large as those of trees or of human beings. Eggs are plump, well-nourished, and sluggish cells. They need to be stimulated to make them active.

5. The Development of Eggs. It was said a moment ago that the egg is a cell. So it is, but there is another fact that must be mentioned about it. **It is not just like the cells of the body from which it comes.** In order to make this clear we must recall a few facts about the structure of cells. In each cell, aside from the more fluid protoplasm, (cytoplasm) there is a definite protoplasmic body called the **nucleus.** In this nucleus there is a very important substance called **chromatin.** As the time approaches for a cell to divide, this chromatin tends to collect into a number of rod-like bodies known as **chromosomes.** The number of these in the body cells of a given species of plants or animals is practically constant. These chromosomes behave in a very interesting way in the development of an egg.

Let us suppose that the nucleus of the ordinary cells of an animal body that produces an egg has sixteen of these chromosomes. By a process which we will not study in detail here, the nucleus of the egg cell **loses just one-half its chromosomes as it prepares for fertilization.** In the supposed case the nucleus of the **ripe** egg cell would contain eight chromosomes instead of the sixteen which is characteristic of the other cells.

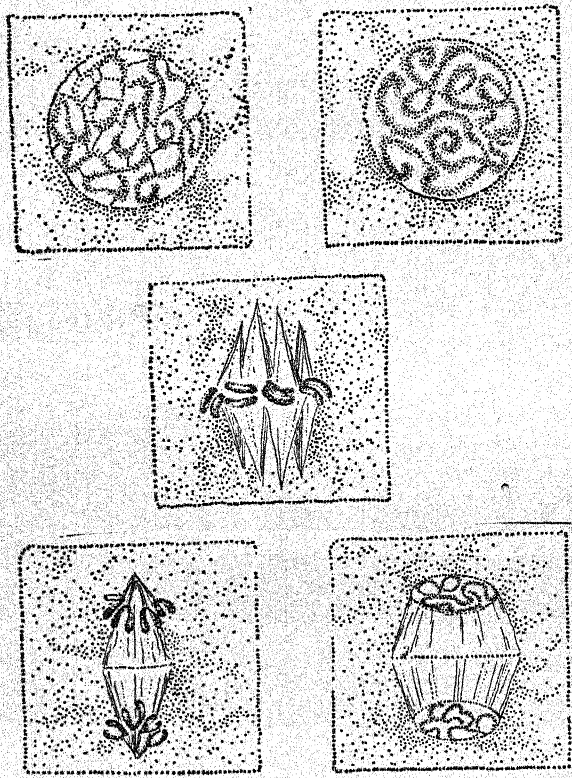

Figure 14. Diagram of the process of division of the cell nucleus. In the first picture the spherical nucleus is seen in the cytoplasm that surrounds it; the net-like arrangement of the chromatin is indicated. In the second the chromatin is in a continuous band, this being the first stage in the division process. In the middle picture the chromatin has resolved itself into definite chromosomes which are dividing at the middle of the spindle. In the fourth picture the newly formed chromosomes are migrating toward the poles of the spindle. The last picture shows the formation of the daughter nuclei and the beginning of the new cell wall. The spindle fibers soon disappear.

This point you must keep in mind. We shall need it to make clear what happens later. **The cells of animal bodies have twice as many chromosomes as their ripe eggs have.**

6. Sperms and Their Characteristics. In many ways, as we have seen, the sperms are opposite in their nature from the eggs. The sperms are always minute, even more minute than the smallest eggs. Animal sperms are almost all quite active, with an active tail or **flagellum** that drives them through the fluid in which they occur. Sperms are real cells, however. They have a perfect nucleus, and a delicate supply of protoplasm, most of which is in the tail mentioned above. Sperm cells vary in shape rather more than eggs. Usually a species produces many more of the small sperms than of the large ova or eggs.

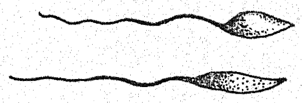

Figure 15. Two examples of animal sperms, very much enlarged.

7. The Development of Sperms. In development the nuclei of sperms of animals behave just as those of the eggs. If the body cells have sixteen chromosomes in their nuclei, these divide, as sperms are being formed, in such a way that each sperm nucleus gets just eight. As the biologist says, there is a **reduction division** in the forming of eggs and sperms by which they get only X chromosomes when there are 2 X chromosomes in the cells of the body of the parent organism. The mother cells of the sperms are not large cells to start with. The divisions that produce the sperms take place rapidly and the protoplasm does not grow much in the meantime. Hence the sperms cannot fall heir to much protoplasm, and so are small.

8. The Reduction Division in Plants. What has just been said about the reduction division in animals does not apply to plants in their formation of eggs and sperms. It

is true, however, that plants, like animals, do have in their life history a reduction in the number of chromosomes which compensates for the doubling of this number that occurs when sperm and egg fuse.

Plants differ from animals in having what is called **alternation of generations**, a phenomenon described in a later chapter. One of these generations **(gametophyte)** bears gametes, the other **(sporophyte)** bears spores, and the two together complete the life cycle of the plant. The reduction division occurs in connection with the formation of the spores.

9. Sex in the Offspring. The differences between the eggs and sperms are not just occasional, exceptional facts. They are very constant differences in the plant and animal kingdoms. Animals and plants regularly produce two kinds of offspring, eggs and sperms; usually neither of these can develop alone; they unite into one individual, and this individual has all the powers of the species. These differences in the gametes are differences of **sex**. They are the most fundamental differences in sex. The eggs and sperms are the "sex-cells." The egg is a female cell, or offspring; the sperm is a male offspring. Fertilization produces a new individual made up of the two kinds of cells.

CHAPTER ELEVEN.

FERTILIZATION.

1. Review of Conjugation. In an earlier chapter a study was made of the union of gametes that are wholly similar. This sort of union is called conjugation, and is quite common among the lower plants and animals. In these gametes there is no outward sign of the differences which we think of as belonging to males and females. We now wish to study the union of eggs and sperms, such as were described in the preceding chapter, where there is a very striking difference in the gametes. These differences are sex differences and we call the offspring sex-cells. Their union we call **fertilization.**

2. The Effects of the Special Development of Eggs and Sperms. In Chapter Ten it was shown that, with all their differences, eggs and sperms agree in one important particular. In both cases, when ripe, they have in their nuclei only one-half the number of chromosomes usual in the cells of the species. There are some interesting results that seem to come from this reduction in the chromosomes. Under ordinary circumstances neither of these cells has the power of dividing again, or of developing any further in any way. There are exceptions to this, but it is true as a general thing. In some of the gametes which are alike we saw that they might resume development separately if they did not happen to unite. In the case of eggs and sperms, unless they unite, both will die. Union, then, has become almost imperative in these special cells. The sperm

is too used up to divide; and the egg has too much protoplasm to be stimulated into division by the small amount of nuclear material in it. They do not behave as young cells. They are like two run-down batteries.

In the second place, these cells are very different in their structure and development. The egg with its large size and rich nutrition is passive and sluggish, while the sperm is reduced to the very lowest living terms. Both these cells are essential to the on-going of the species. Their very differences, therefore, will make it absolutely sure that the powers they have and the work they do must be very different.

Eggs develop much more slowly, sometimes requiring years; are usually produced in much smaller numbers; have no ability to take an active part in the mating, but secrete substances that attract the male cells. The sperms, on the contrary, are actively sensitive to the substances secreted by the egg or its surrounding tissues, are produced rapidly and in enormous numbers, swim actively about and find the female cells. It is thus seen that their powers and behavior are strongly **complementary** and that they are wonderfully adapted to each other: passive and motile, secretion and sensitiveness, attraction and responsiveness, large amount of food substances in protoplasm and almost no protoplasm at all. This adjustment between male and female gametes is the most fundamental fact of sex and mating, and helps determine all the other facts to which we shall give attention later.

3. Method of Fertilization. In the union of the sperm with the egg there are two distinct problems. One is the actual task of uniting these two cells into one when they have come into the same region. The other is that of bringing the sperms and eggs into such close range that they can have any chance of uniting. This latter problem must be solved by the parents that produce the cells, and is solved in very different ways in different plants and animals. It will be considered in the next chapter.

As has been suggested above, the eggs have much attraction for the sperms when they come near to one another. The sperms move toward the egg, attach themselves to the surface, and one of them (usually only one) succeeds in penetrating the egg membrane. The sperm enters the protoplasm of the egg. When it is in

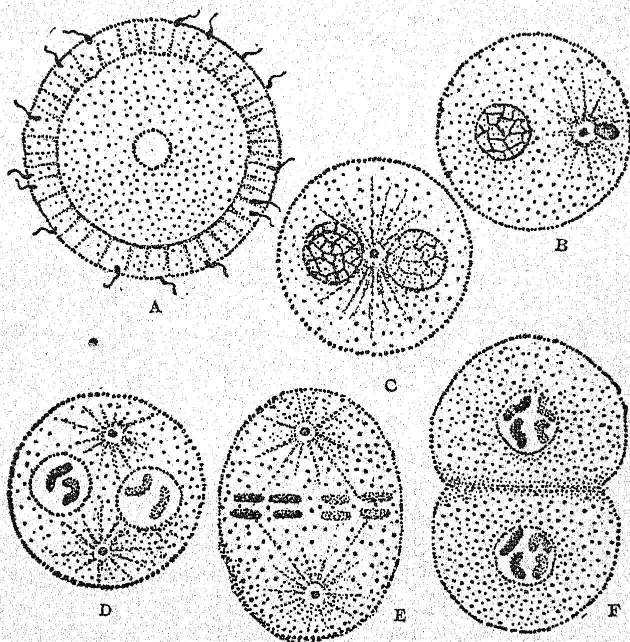

Figure 16. Diagram of the process of fertilization in one of the lower animals. *A*, sperms entering the outer region of the egg. *B*, one sperm only has entered the inner part of the egg and has altered as indicated at the right. *C*, the nuclei of sperm and egg are now similar in appearance. *D*, a stage of the process in which the chromosomes become distinct. *E*, splitting of the chromosomes. *F*, first division of the fertilized egg, with maternal and paternal chromosomes equally represented in the daughter cells.

the protoplasm of the egg it looks like a new nucleus. The egg also has its own nucleus; hence the egg is now a cell with two nuclei in it. These two nuclei exert an attraction for each other; they gradually move together through the protoplasm, and finally fuse.

5. The Union of Egg and Sperm: Its Results. The process described above is called fertilization and is found in practically all the higher animals and plants. In nature it is much like the conjugation described for the lower plants and animals, and may have been developed from it. When the full union of the sperm with the egg has been finished, we have a well nourished cell with a nucleus made up of two parts, coming equally from a male and a female cell. The protoplasm and food of this cell, on which further growth is supported, come almost entirely from the female cell.

The make-up of this new nucleus is peculiarly interesting and important. The student will recall that the nucleus of the egg, as it ripened, lost one-half of its chromosomes. That is to say, if 2X is the number of chromosomes found in the cells of the body in a given species, these are reduced to X in the egg. The same is true of the sperm nucleus. Therefore, when these two bodies unite, they bring to the union two nuclei of just one-half value so far as chromosomes are concerned. When they unite the nucleus is completely restored to the proper number of chromosomes. Whatever was lost has been restored; and, instead of being from one source only, the new cell has material in it usually coming from two individual and distinct parents. It is now known as a **fertilized egg.**

Recall that the forming of the fertilized egg is not **reproduction.** Reproduction gave the egg and the sperm cell. They were the offspring of their respective parents—two quite different kinds of offspring. The eggs and sperms were male and female individuals. They were so feeble that both of them would have died but for their

union. When they unite there is only one individual where there were two before. This is just the opposite of reproduction, which gives two individuals where there was only one before. **But this new individual has powers of development which neither of the cells that entered into it had.** Instead of being feeble, as these two cells were, it is completely renewed. It has youth and the power to grow into an adult of the species to which it belongs.

A fertilized egg, then, is the result of a union of two individuals from different sources. Each adult is not one offspring merely. It is a composite made up of two offspring, a male and a female.

6. Fertilization and "Blood." We have a saying that "blood will tell," and we mean by it that good or bad qualities in the parents are sure in the long run to crop out in their descendants. The reasons for this always interest us. This wonderful process of fertilization throws some light on the fact of inheritance. We know that everything that is actually inherited, in the biological sense, comes by way of these sex cells. To be sure, parents can influence and change their offspring in other ways than this, but such influence is not inheritance.

Now if this is true, we can make some valuable conclusions from what we have. All the protoplasm outside the nucleus came from the mother; the matter in the nucleus, and only that, came equally from both parents. But so far as we can see, in the long run, **offspring are no more liable to be like the mother than like the father.** These facts show pretty conclusively that **those qualities in which the parents are unlike are carried somehow by the nuclei,** because only the nuclei come equally from both parents. It is clear that likeness to one parent or the other is not determined by bulk of protoplasm; otherwise the female characteristics would be much more likely to be transmitted than those of the

male. It is believed by many students of the subject that they are carried by the chromosomes which are so equally shared by the male and female in fertilization.

7. The Narrow Bridge. Genetics is the name of a division of biological science; it is the experimental study of evolution and heredity; its aim is to ascertain the knowledge that is necessary for the improvement of inherited characters; it is a division of science which has already led to great improvements in the races of domesticated animals and cultivated plants and it holds the promise of great results in the improvement of the human race. In his very interesting book on that subject*, Professor Walter has a paragraph which reads about as follows:

"Whatever may ultimately prove to be the **determiners** of the hereditary characters which appear in successive generations, it is evident that they are located in the fertilized egg. This single cell is the actual bridge of continuity between the generations. Moreover, it is the **only** bridge.

"For the majority of animals the egg develops entirely outside of and independent of the mother, thus limiting to the egg-cell itself all possible maternal contributions to the offspring. Although there is abundant evidence that half of the filial characteristics come from the male parent, the only actual fragment of the paternal organism given over to the new individual is the single sperm-cell. Thus the entire factor of heritage is packed into the two germ-cells derived from the respective parents and, in all probability, into the nuclei of these germ-cells, since the nuclei are apparently the only portions of these cells that invariably take part in fertilization.

"When it is remembered that the human egg-cell is only about 1-125 of an inch in diameter, and that this is a gigantic size as compared with that of the human sperm cell, and, furthermore, when one passes in rapid review

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**Genetics, H. E. Walter, The Macmillan Company.*

the marvelous array of characteristics that make up the sum total of what is obviously inherited in man, **the wonder grows that so small a bridge can stand such an enormous traffic.** A sharp-eyed patrol of this bridge that is the strategic focus of heredity is proving to be one of the most effective points of attack in the entire campaign of genetics."

8. Artificial Fertilization. The process described in this chapter varies considerably in different species of animals and plants, but what has been said will serve to give you an idea of what occurs in the great majority of eggs and sperms that develop into adult plants or animals. Usually an egg dies and disintegrates if it is not fertilized by a sperm nucleus. However, a most wonderful discovery was made only a few years ago. Some eggs of sea-urchins were experimented with. Now the eggs of sea-urchins, so far as we know, never develop without being fertilized. But a scientist took such eggs directly from the ovary, where they could not have been exposed to sperms, and by putting them in water of a different density from that of ordinary sea water and then returning them to the sea water, he succeeded in having them begin to develop, instead of die and decompose as they would naturally do without fertilization. In other words, by outside chemical stimulation, eggs were "artificially fertilized," so that they began to develop without uniting with sperms. This work has been repeated many times since, and we find that the same thing is possible with many different kinds of eggs; of worms, mollusks, and even of vertebrates. It is also found that numbers of other chemical substances and even other kinds of stimuli may so arouse these eggs as to start development. All of this suggests that the work of the sperm is to act as a stimulant to the sluggish egg, and cause it to become active in development, when it could not do so unaided.

CHAPTER TWELVE.

DIFFERENT KINDS OF PARENTS.

1. Review of Beginning of Sex in Offspring. We have seen that the striking differences between eggs and sperms are rather constant for all higher organisms. These differences are the first signs of sex; indeed they are the most important elements in sex. We call the egg a female gamete and the sperm a male gamete. It is important to remember that the gametes are the **offspring** in reproduction. They do not merely unite and develop into offspring. When **they** are produced the parent has "reproduced." Reproduction consists in the formation and the separation of these male and female cells from the parent. All the other facts of sex with which we are familiar come from this starting point.

2. Simplest Cases in Which Eggs and Sperms are Found. You remember that there are no eggs and sperms in the simplest form of reproduction. There we see merely fission or budding from one parent, with no union of any kind. The simplest unions we have discovered are those of conjugation, in which two similar cells, often from the same parent, unite. From this we pass gradually to different kinds of gametes which regularly unite. In some cases eggs and sperms are produced by the same individual. They may be produced at the same time or at different times. A parent which produces both male cells and female cells cannot rightly be called either male or female. It is called an **hermaphrodite.** The word is

derived from Hermes and Aphrodite, Greek male and female gods.

Many of the lower plants, and some of the simpler animals produce both kinds of gametes in the same individual. In such a plant as Vaucheria, or Oedogonium, or some of the moss plants, both kinds of gametes are produced near together on the same plant.

In the fresh-water hydra, described in Chapter Four as reproducing by buds, reproduction by gametes also occurs. In this little animal eggs and sperms are formed at somewhat different parts of the body, and each hydra is, so to speak, one sex at one point and the other sex at another point.

This state of having both sexes in one organism is known as **hermaphroditism.** In addition to the instances mentioned above, it occurs regularly in many of the worms, in snails, oysters, etc. Hermaphroditism may occur in occasional individuals of higher species, even among the vertebrates.

3. The Organs That Produce Eggs and Sperms. Although a plant or an animal may produce both male and female offspring at the same time, it is usually true that such a parent has special and different organs for each. Often they are definitely located at different parts of the body.

The organs that produce the gametes are quite differently named in different organisms. Generally among animals the male organ, which produces sperms, is known as a **spermary** or **testis,** and female organ is called an **ovary.** Among plants the organ that produces sperms is called an **antheridium.** The female organ in which the egg is produced is called, in different groups, **oogonium** or **archegonium.**

Where gametes are alike, there is only one kind of organ to produce them. There is no reason why there should be more. When the gametes become different,

the sex of the cells seems to be stamped on the organs that produce them. An experienced biologist can usually tell which sex an organ represents, even though he has never seen the organism before. The sex quality of the organ becomes as marked as that of the gametes themselves. The gametes are specialized. The organ that produces them becomes equally so.

4. **Specialization of the Parents.** Where the gametes are alike, there is no difference in the organs that produce them, and the parents are all alike. But a step higher up we also find different kinds of gametes, produced in different types of organs, but all in one kind of parent. One of the very best illustrations of this in the animal kingdom is the common earthworm. In certain segments of its body-cavity it produces sperms; in other segments it is producing eggs. Each earthworm must perform all the duties of father and mother.

But in the very same group of worms, in some of the marine forms, we find a surprising difference. In these one animal produces one or the other kind of gametes; not both. If one segment of these worms produces sperms, all the segments produce sperms, and the whole animal is a male. Other worms produce eggs only. These eggs and sperms from different animals must unite. Here we have sex in the gametes; sex in the organs that produce the gametes; and sex in the individual that bears the organs. Beginning with the differentiation of eggs and sperms, differentiation of sex has worked back into the parents which produce them. This is the first time that we have found organisms permanently and wholly male (father) and female (mother) in a strict sense. In some animals in which sex is distinct the differences between males and females cannot be detected externally, though there are internal differences.

5. **Further Differentiations of Parents.** This difference in the sex organs is the most fundamental difference in

the parent. All other differences are secondary to these and grow out of them. The task of forming and caring for eggs is so different from the task of forming and caring for sperms that the parents, at first differing only in the internal organs that produce gametes, come to differ in many external particulars. This is known as **sex-dimorphism.** This is the state we are most familiar with in the higher animals and in man. The males and females of most higher animals are more or less conspicuously different from one another. It very often happens that the males of a species of birds, we will say, differ more in general appearance from the females of that species than they differ from males of an entirely different species. Put in another way, if we were to find the male and female of the rose-breasted grosbeak apart in nature without any chance to find out the facts about them except by external appearance, we should undoubtedly think they belonged to different species. These external differences between males and females of a species are found in birds, in many mammals including man, in some fishes and amphibians, and in many insects.

6. Nature of External Difference between Male and Female Parents. It is not possible here to call your attention to all the ways in which the bodies of male and female parents differ. The differences are greater in the higher and more active animals. In general the males are more highly colored, stronger, fiercer, and more active. They often have special organs of combat, and instincts to use these. The female is usually more retiring and less endowed with instinct to seek out her mate or to fight other members of the species. Her structures and instincts relate more to care of the young. You can find many illustrations of these statements, as well as some exceptions to them, by field observation of birds, mammals, frogs, insects, and spiders.

7. The Causes of the Differences. We are reasonably

certain that the development of the sex organs and of the cells within these is the chief cause of the differences we see between male and female animals. For example, in the very early development of an individual it is usually impossible to tell which sex an animal is going to be. It is only as the testes and the ovaries develop that the external signs of sex are shown. If we take a male chicken in early life and remove its testes, it will fail to develop spurs and some other external signs of its maleness. Much the same thing is true if the ovaries of a young female chicken are removed. It is much more difficult to see any difference between a male and a female thus deprived of the internal sex organs than between the normal, natural sexes. This shows that it is the sex cells that determine the nature of the parent body rather than that the nature of the parent body determines the sex cells.

8. The Advantage of these Differences. We know that the developing testes and sperms **put into the blood materials that stimulate the growth of the male characters** even in such remote parts as the vocal organs, muscles, and so forth. It is the presence of these substances that stimulates the growth of muscles and nervous system. If these substances are absent because of removal, or because of abuse of the developing sex organs, the physical and mental qualities do not develop normally.

You may wonder what value these differences between males and females have. Or you may take for granted that the sexes should be different and ask no questions about it. Why should the males differ in so many ways from the females? Is there any advantage to the species in having them different?

We have seen that sperms and eggs stimulate the individuals producing them very differently. There is, however, another side to the matter. The task of the male, the work done by him, and the service rendered

the race by the sperm cell and the male parent, are so different from that rendered by the egg and the female, that the very doing of the necessary work of the two sexes results in differences, just as the farmer becomes different from the banker or teacher by giving his time and thought to different things.

We have seen that the egg cell is large, passive, and highly nourished, while the male cell is minute, poorly nourished, and exceedingly active. When these gametes unite, it is the egg that attracts, while it remains passive, and it is the male cell that is aroused by the presence of the egg and actively seeks out the female cell and unites with it. The role or function of the two cells is different. It is inevitable that the parent that produces eggs, if it is to do its proper motherly work, will become modified in nature and instincts and in structure by producing the eggs and bringing them to the proper condition for fertilization. Similarly, the structures and the instincts demanded of the parent that is to produce sperms will be very different from those of the mother.

We can thus see that certain internal forces are at work making male parents and female parents different, and that there are duties and tasks suitable to each, so different from the other, that the internal differences will be used and increased by use.

CHAPTER THIRTEEN.

MOSSES AND FERNS

1. General Grade of Development. Just above the green water plants, called algae, and the colorless fungi, including molds, mushrooms, toadstools, and the like, we find some green plants that begin to look more like the higher plants with which we are familiar. Among these are the mosses and ferns. In them we find for the first time a clear differentiation between roots that take up water, leaves that manufacture food, and stems that connect the leaves and the roots. The lower plants have no such clear differentiation of their bodies.

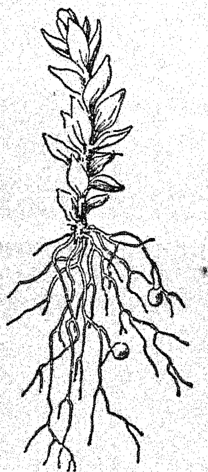


Figure 17. An individual mature moss plant, showing general similarity of its body to that of higher plants. *From Coulter's Plant Life and Plant Uses.*

The mosses and ferns are not so well developed as the higher seed-bearing plants, but they have so many of the characteristics of the higher plants that no one can get a real understanding of the seed-plants without a study of these lower forms. Furthermore, the method of reproduction in mosses and ferns will help us understand what happens in the higher plants.

2. The Life Cycle in a Moss. This life history is more complex than anything we have yet described, but it will well repay careful study.

a. The Germination of the Spore. If we start with a spore, we find that after a longer or shorter period of rest it germinates. This means that the soft, inner living part swells, bursts the old spore wall, and sends out a tube. This tube becomes green, like a filamentous alga, manufactures food, grows, and branches abundantly. The whole thing at this stage is called a **protonema,** the word referring to its thread-like appearance. This stage is not usually noticed.

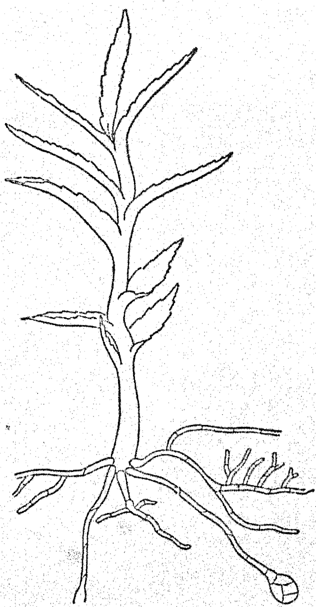


Figure 18. A young moss plant (magnified) arising from the protonema. *From Coulter's Plant Life and Plant Uses.*

b. Budding. Bud-like outgrowths next appear at various points on these threads. These buds do not grow into new threads like the old ones from which they spring, but divide in such a way as to form upright stalks or stems. Each of these stalks develops root-like structures and leaves, lengthens considerably, and becomes one of the leafy moss plants with which we are all acquainted.

c. Formation of Gametes and Fertilization. At the

top of this leafy stalk there is sometimes a thick cluster of leaves. At the tip of the stem, in the tissues surrounded by these leaves, the moss plant develops two kinds of structures not found elsewhere on the plant. One of these is like a minute flask with a very long narrow neck. This is really a kind of ovary or female organ, and it is called an **archegonium.** In the bottom of the flask is a large, plump cell, which is the egg. The other kind of organ that develops at the top of the stem is club-shaped, being attached to the end of the stem by its stalk. This is a male organ and is called an **antheridium.** When the antheridium is mature it bursts, and from it escapes a great number of minute, ciliated, free-moving cells. These are sperms. The bursting of the antheridium occurs when the end of the stem is moist, as when a drop of dew or rain is among the leaves. Through this moisture the sperms swim about until they come near a fluid secretion produced by the **archegonium.** They are attracted by this secretion. Some of them swim down the neck of the flask, and one of them unites with the eggs at the bottom, thus fertilizing it.

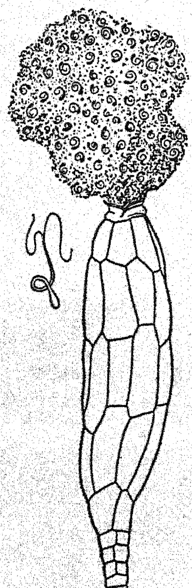


Figure 19. Antheridium of moss discharging sperms; much magnified. *From Coulter's Plant Life and Plant Uses.*

In the moss we have one kind of parent plant with two kinds of sex organs which produce two

entirely different kinds of gametes. In other words, the moss described is **hermaphroditic.**

d. The Sporophyte and the Formation of Spores. Evidently we now have a fertilized egg. Judging from what we have learned of animals, we might expect this fertilized egg to escape and to develop directly into a new moss plant. But it does not do this. **It begins to divide right where it is** in the bottom of the flask at the top of the upright stem. It develops a mass of cells, known as a **foot,** that connects it with the tissues of the mother plant. Just above this is a delicate stalk that may become an inch or more long, called the **seta.** At the top of this is a swollen portion, the **capsule,** in which spores develop. All this develops from the fertilized egg. The whole structure is known as the **sporophyte,** because its work is to produce spores. It has no leaves and gets the nourishment necessary to grow and mature its spores from the leafy moss plant which is the **gametophyte.** (See page 58.) Within the capsule certain cells by their division produce numerous spores; these finally escape from the capsule and the cycle is completed. We are back to the point at which we started, the spore that germinates.

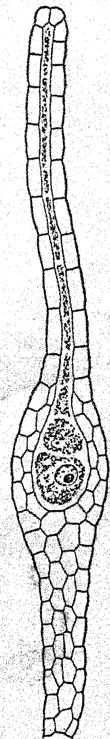


Figure 20. Young archegonium of moss; much magnified. *From Coulter's Plant Life and Plant Uses.*

3. Summary of Reproduction in the Moss. In this life cycle we have found that the moss has three methods of forming more plants, i. e., of reproducing: (1) The formation of spores in the capsule; (2) the budding of the protonema by which erect moss plants are formed; and (3) the formation of the gametes, by the union of which the sporophyte arises. (Any generation of plants which produces spores is a sporophyte, but that particular kind of sporophyte we find in mosses is called a **sporogonium.** The visible parts of all flowering plants are parts of the sporophyte generation.)

4. The Life Cycle of the Fern. In middle and late summer we find on the under surface of the leaves of ordinary ferns numerous spots. These contain many spores which escape in due time. As in the moss, we will begin with the spore.

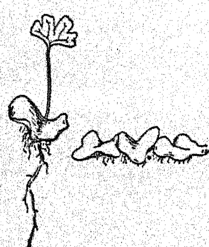


Figure 21. Prothallia of fern. The figure at the left shows a young sporophyte into which the fertilized egg has developed. *From Coulter's Plant Life and Plant Uses.*

a. Germination of Spore and Formation of the Gametophyte. The spore germinates by sending out a tube as in the moss, but instead of forming a long-branched filament, it divides in all planes and makes a small, flat, heart-shaped green body known as a **prothallium.** This is not likely to be seen by the student unless his attention is called to it. It will grow only in moist places. It lies flat, has delicate root-like structures **(rhizoids)** on the under side, and a notch at the growing end. This prothallium is the gametophyte generation.

b. The Formation of Gametes and Fertilization. The green upper side of the gametophyte receives the

light, and its cells manufacture foods as do the leaves of the higher plants. At certain points on the under surface two kinds of bodies are formed, with exactly the same names and the same functions as those that grow at the top of the leafy moss plant. The archegonium is much the same shape as in the moss, but the antheridium is more flat and rounded. The sperms, as in the moss, must have moisture in which to swim to the archegonium. The egg at the bottom is fertilized just as in the moss.

c. **Development of Sporophyte and Formation of Spores.** The fertilized egg divides, and the four cells formed by the first divisions develop into the parts of the new plant. Unlike the moss embryo, the fern embryo does not depend long for nourishment on the small gametophyte. As soon as its growth causes it to break out of the small cavity of the archegonium, it begins to develop roots that take hold of the soil and leaves that manufacture food for further growth. Furthermore, instead of stopping with a small seta and capsule, growth continues in the fern sporophyte until we frequently have a rather large plant with roots and numerous handsome leaves. Later in the season these leaves produce on their under surfaces the spores with which we started.

5. **Comparison of Moss and Fern.** It will be seen from the above that the moss and fern follow very much the same course of development in their life cycle: spore germination; development of the plant that bears gametes; formation of gametes; fertilization; development of the embryo into another generation of the plant wholly different in appearance from the gametophyte; the development of spores by this new generation (sporophyte); the escape and germination of the spores.

It will be noticed in both kinds of plants that when the spores germinate they produce a plant that **forms gametes and not spores**; and when the gametes unite they start a plant that **develops spores and not gametes. We have in both a regular alternation of two different kinds of individuals in one life cycle.**

There are also some interesting differences:

Moss	Fern
1. The gametophyte is a leafy plant; the most conspicuous part of the cycle; the part called the "moss-plant."	1. The gametophyte is a poorly developed part; the poorest part of the cycle; the part called the prothallium.
2. The sporophyte is wholly parasitic on the gametophyte, and develops only slightly, being composed of foot, seta, and capsule. It is called a sporogonium.	2. The sporophyte soon becomes independent of the gametophyte, fixes itself to the soil, develops leaves and roots and is the real "fern plant."

CHAPTER FOURTEEN.

ALTERNATION OF GENERATIONS.

1. Summary of Reproductive Methods. We may class the methods of reproduction that have been studied as follows:

1. Those that occur without union of gametes, as in fission, budding, spore formation, etc. (non-sexual).
2. Those that involve union of gametes, whether similar or unlike (sexual).

We have studied many forms of plants and animals in which both non-sexual and sexual reproduction are found. For example, hydra buds and also produces eggs and sperms; many of the algae reproduce both by swimming spores and by gametes. In the forms referred to, however, we must note one important fact: the final organisms produced by the two methods were **alike.** We could not tell by looking at an individual hydra whether it had been formed as a bud or had come from a fertilized egg.

2. Alternation of Generations. There is another step in the story which we must now master. It often happens that this reproduction by union (sexual) and reproduction without union (non-sexual) occur in the same species, in regular alternation, as we have seen in mosses and ferns. Furthermore, the individual that results from non-sexual reproduction is different from the individual formed by the union of gametes, usually so different that no one would take them as belonging to the same species. This is called **alternation of generations.** If we illustrate by

letters, we may describe such an alternation in this way: An individual **A** reproduces non-sexually, and when the offspring become mature they are not **As**, but **Bs**. **B**, when mature, develops gametes which unite, and the fertilized eggs develop into organisms that are not like their parent **B**, but like the grandparent **A**. **A** by budding or spore-formation produces **B**; **B**, in turn, by sexual union, produces **A**.

3. **The Moss and Fern Illustrate this Alternation.** What has been described in the preceding section is exactly the thing that happens in the mosses and ferns. The small prothallium in the fern, which has been called the **gametophyte**, has the two kinds of gametes. These unite, start a new plant, which is the large fern plant that grows to be very different from the little microscopic prothallium. This large plant is the **sporophyte** generation. It has a period of growth, and when it becomes mature it cannot in any way produce eggs and sperms, but produces great numbers of spores without any sexual union whatever. We have seen that these spores germinate into the gametophyte. The sporophyte is one generation and the gametophyte is another. These generations regularly alternate.

In the moss we have exactly the same facts and in the same order. In the fern both generations live independent lives and the sporophyte is the better developed generation. In the moss the gametophyte is the more important generation and the sporophyte is parasitic on it. One question about the moss may very properly be raised by the student at this point. How do we know that the structure that bears the spores in the moss is **really a new generation and not merely a part of the regular moss plant**, as it looks to be? That it is a new generation is shown by the fact that it is **produced by the development of a fertilized egg. We know always that a new generation begins when we start with a fertilized egg.**

In mosses and ferns, then, we have a good example of alternating generations, in which the spore is the beginning of the gametophyte generation of the plant, and the fertilized egg is the beginning of the sporophyte generation.

4. The Behavior of the Chromosomes in the Life Cycle of Mosses and Ferns. In Chapter Eleven it was shown that mature eggs and sperms have only X chromosomes in their nuclei before they unite, 2 X being the number found regularly in the body cells. When the gametes have united, the number of chromosomes is thereby doubled. The alternation of generations in the moss and fern shows this in a very interesting way. If we start with the fertilized egg, after the union of the gametes has brought the chromosomes up to 2 X, we find that the following cell divisions give to all the daughter cells of the developing sporophyte 2 X chromosomes. This continues to be true until just before the spores are to be formed. At this time a reduction division occurs, similar to that described in Chapter Ten, and the spore has only X chromosomes. When the spore germinates, and divides to form the gametophyte, its descendant cells continue to have X chromosomes all through the life of the gametophyte. The gametes formed in this gametophyte also possess the X number of chromosomes, and are consequently ready to unite. At their union the nucleus becomes 2 X once more.

5. Alternation of Generations in Animals. Alternation of generations is much more common in plants than in animals, but we have some very interesting examples of it among animals. Indeed, we first knew of it among animals. In the group of animals to which the fresh water hydra belongs, there are many species similar to hydra. Most of them differ from hydra in that when they form new individuals by budding, the new individuals do not escape and become independent, but remain attached. The result of this is finally a colony of

many attached individuals that have arisen by budding from a single parent. After a period of this kind of budding, the colony forms other buds of a different shape and structure. When these mature they detach themselves and become free swimming jelly-fish. No naturalist, discovering them swimming in the water, unless he knew the facts just stated, would ever suppose for a moment that these jelly-fish were in any way related to the colony from which they actually came. The free jelly-fish produces gametes, which unite sexually and form embryos. When the embryos develop they are not like their parents the jelly-fish, but are like their grandparents, the tubular hydroids. They settle down and reproduce by budding.

Many such instances are found in the coelenterates (that branch of the animal kingdom to which the hydra belongs) and among the parasitic worms, such as liver flukes, tape worms, and the like.

6. Some Advantages in Alternation of Generations in Animals. We do not know what forces have brought about alternation of generations, but we can see that it may be of some advantage to the organisms having it. It gives a kind of double chance for organisms to scatter and to become adapted to life conditions. For example, in attached forms such as hydroids, the budding enables a single individual that manages to become attached in a favorable place gradually to take complete possession of that spot by budding. Being attached has advantages, but it also has handicaps. If conditions change, the colony may be destroyed. Besides, there is no chance in budding for wide distribution. Now the formation of another kind of individual which is free-swimming, and able to produce eggs and sperms, gives the fixed colony a chance to spread its offspring widely and to seek out many favorable localities for growth. In this way the advantages of both methods are combined in one species.

In the parasitic form, the alternation is often an aid in

getting back and forth from one species of host to another, as is so often necessary. For example, the liver fluke is in the snail for a while, in the liver of the sheep a while, and in the water of the pond between times. It is during these alternations of generations, with their differences of structure and habits and instincts, that these perilous changes are made.

CHAPTER FIFTEEN.

SOME EGGS THAT ARE NOT FERTILIZED.

1. The Fate of Eggs. As we have seen, some of the eggs formed by plants and animals are fertilized by the sperms and then may develop into mature plants or animals. But a great many fail to be fertilized, and such eggs, no matter how perfect they are, cannot preserve their life under ordinary circumstances. Such finally die and decompose. Investigators have found that they can take the eggs of many of the lower animals while they are in good condition, even though they have not been fertilized, and, by changing the external conditions about them in certain ways, stimulate them to begin development as though they had been fertilized. (See page 65.)

2. Parthenogenesis. There is one other exception which is so remarkable as to demand attention. Quite a number of organisms regularly produce eggs that develop into the adult **without fertilization by the male cell.** We do not know whether they are stimulated in some special way while in the body of the parents, or have the power within themselves to develop without any stimulus. This development without fertilization is **parthenogenesis.** The circumstances under which it takes place are different in different organisms. In some cases, as in the queen bee, the mother can, apparently, determine at any time whether the eggs shall be fertilized or not. In other cases, as in some of the rotifers (microscopic animals), the non-fertilized eggs ("summer eggs") are laid at certain seasons

of the year and the eggs requiring fertilization ("winter eggs") are produced at other seasons. In some cases the mothers may differ, some forming both summer and winter eggs and others parthenogenetic eggs only.

Furthermore, there is occasional parthenogenesis even among forms where fertilization is the rule. For example, it is known that the sporophyte of ferns may sometimes develop from cells of the gametophyte without fertilization.

3. **The Case of the Honey Bee.** Perhaps the best known case of parthenogenesis is that of our common bees. The queen, who is the one perfect female of the hive, receives a large supply of sperms at mating. This is stored in a sac opening into the duct along which eggs come from the ovaries on their way outwards. It is believed that the queen can control the sperm supply in such a way that eggs may pass to the surface either with sperm or without. In doing this, the queen is doubtless controlled by temperature, food, the conditions in the hive, the size of the cells provided for the eggs, etc. When she forces out sperms on the passing eggs and they are fertilized, they develop into the workers (females). If the eggs are not fertilized, they develop into the males (drones). While the workers are females, they are not perfectly developed females as the queen is. Apparently any fertilized egg may develop a queen if the larva is specially nourished to that end. Observers claim that the workers may lay unfertilized eggs that may develop. There are many cases of parthenogenesis found among the kindred of the bees, the other social insects, such as bumble bees, wasps, ants, etc. Some of these are as interesting as the case of the honey bee, but they are not so well known to the general student.

4. **Hydatina, the Rotifer.** This little "wheel animalcule," of about the grade of development shown by worms, is found in stagnant water. Its life history has been very well studied. There are three kinds of eggs produced,

"summer eggs" of two sizes, and "winter eggs." The summer eggs are thin-shelled and are not fertilized. The larger ones develop at once and produce females. These females may in rapid succession produce several generations of parthenogenetic females. Later in the season, these females lay the thick-shelled winter eggs, which must be fertilized in order to develop. About this time the males appear, hatched, seemingly, from the smaller summer eggs. After fertilization, the winter eggs lie dormant through the winter and develop, with the return of warmth, into the females with which we began.

It has been found that external conditions, such as temperature, state of the water, food, etc., have a part in determining the kinds of eggs produced and the length of the parthenogenetic generations.

5. The Aphids, or Plant Lice. A condition similar in many respects to the last is found in the aphids, a group of small sucking insects that are parasitic on the tender twigs, roots, and leaves of many plants. In the autumn there are females and males, and the eggs are fertilized. These eggs are attached to the twigs of the host plants in crevices where they may be partly protected. In the spring they hatch out into females, which in their turn lay eggs that hatch without fertilization. All the offspring at this time are females with this power of laying parthenogenetic eggs. This may continue for ten or twelve generations, giving rise to an unthinkable number of offspring which may be a great tax on the host plant. Finally, in the autumn, a generation is formed that includes both males and females. These mate and the fertilized eggs go over the winter, as described at the beginning, until the following spring. In some aphid mothers, the parthenogenetic eggs develop before they leave the body and the young are thus brought forth alive (vivipary).

6. Parthenogenesis and Non-Sexual Reproduction. At

first thought it might seem that parthenogenesis is just one of the non-sexual methods of reproduction, like budding or spore formation. A spore is a reproductive cell that can develop without fertilization. Then why is not parthenogenesis a form of spore reproduction? Two or three facts, however, make us realize that parthenogenesis is more related to sexual reproduction. In the first place, the parthenogenetic cells are produced in ovaries, where eggs arise; and in the second place, in such forms as the bees, it seems that any egg may become either a fertilized egg or a parthenogenetic one. It would seem, therefore, that parthenogenesis is a case where the process has gone backward; where a cell that might be expected to unite has given up union and has come to develop without it.

CHAPTER SIXTEEN.

THE FAMILY OF THE FROGS

1. The Family Tree. A great many of our examples in the earlier part of this book have been taken from the plants and the lower animals, the **invertebrates.** The frogs, along with the fishes, birds, and men, are **vertebrates.** The class of vertebrates to which frogs belong is not a very large or important one, but it is one of the very most interesting because of its method of reproduction and development. In the family are frogs and toads, tailless forms, including many kinds of tree toads; and a number of slimy animals with tails, somewhat like lizards, that live in water or moist places. These latter are newts, salamanders, sirens, "mud-dogs," and the like.

The frogs and toads breathe in the air, and may live on land, but they (the frogs, particularly) spend much of their time in or near the water. Most of the family would die if long out of water.

2. Reproductive Habits of the Frog. The frogs have two sexes. The mother lays large masses of eggs in the water. The egg proper, which is about the size of medium shot, is dark in color and is surrounded by a layer of clear transparent gelatin which helps to hold the eggs together in globular masses or in strings, depending on the species. Frogs do not lay eggs in nests, or specially prepared places; but the frogs and even the land toads go regularly in early spring to the shallow margins of pools and streams. The eggs are frequently attached by the gelatin

to sticks or leaves of grasses or to other stationary objects in the water.

3. Mating and Fertilization. While the mother is laying the eggs in the water, the male frog pours out great numbers of sperm cells over them, also in the water. These sperms can swim, and under the attraction of the eggs one sperm cell unites with each of the eggs. The gelatin is not a living part of the egg, and therefore the sperm must pass through this until it reaches the dark cell within. The head of the sperm containing the nucleus passes into the egg proper and unites completely with the nucleus of the egg. This forms a fertilized egg or embryo with all the powers of developing into a mature frog.

4. The Early Development. If we were watching one of these eggs with a microscope, we should see, about two hours after fertilization, a little groove passing round the egg and marking it off into two hemispheres. This shows that the one-celled embryo has now become two-celled. A little later it divides again, at right angles to the first division, into four cells. These four cells are equal. Soon other walls appear at right angles to both of those previously formed. These new walls divide each of the four cells into two, one of which (the upper) is considerably smaller than the other. Divisions of all the cells continue to take place rapidly. By the end of twenty-four hours there are too many cells to count.

During this time the embryo, while changing its shape a little, is not larger than it was at the start, yet there are hundreds of cells where there was one at first. It follows then that the cells in dividing have become much smaller. Yet each has a little mass of protoplasm, a nucleus, and all the other parts that a cell is entitled to have. Furthermore, each one of the 2X chromosomes in the nucleus made up of the union of male and female nuclei splits with every division, and thus every nucleus has still 2X chromosomes.

The first difference in these young cells showed at the eight-celled stage when we had four small and four large cells. At this time we know that the small cells are to make the outer part of the skin, the nervous system, and the sensitive parts of the animal generally. The larger cells will give rise to the digestive tract and its glands. These cells then are different, although they are all descended from the same cell at the beginning. This is called **differentiation.** The cells, from this time on, differentiate more and more. Some of them become nerve cells, some become bone, others become gland cells, muscle cells, connective tissue, blood cells, pigment cells, and so forth.

In three or four days changes enough have occurred to enable us to see at a glance which end is to be head and which tail; which side is to be back and which belly; which right and which left. In a few days more, the young tadpole breaks out of the envelop of gelatin and we say it is hatched. From this point on it leads a different life, because its environment is greatly changed.

5. The Life of the Tadpole. As the young frog, which is called a tadpole, develops, it has organs suiting it to life in the water. It has a soft skin that would dry up in a few minutes in the air, it has gills by which it takes its oxygen from the water, it has a fin-like tail by which it swims freely, it has no legs that would enable it to walk. In a word, it is a water-living, fish-like creature with no adaptations whatever for an air and land life. During a period varying from three or four months to two years, depending on the species and the conditions of life, this tadpole may continue. During this time it eats vegetable matter. The tadpoles of the large species like the bull-frog may become three or four inches in length.

6. The Great Change. If the tadpole stopped here, his history, perhaps, would be as interesting as most others. He might be considered a strange kind of fish. But he

does not stop here. His later behavior is one of the surprises of nature. Usually during the same summer in which he hatched, he begins to undergo some changes that almost make him over into a new animal. These are both inside and outside changes. On the outside he begins to

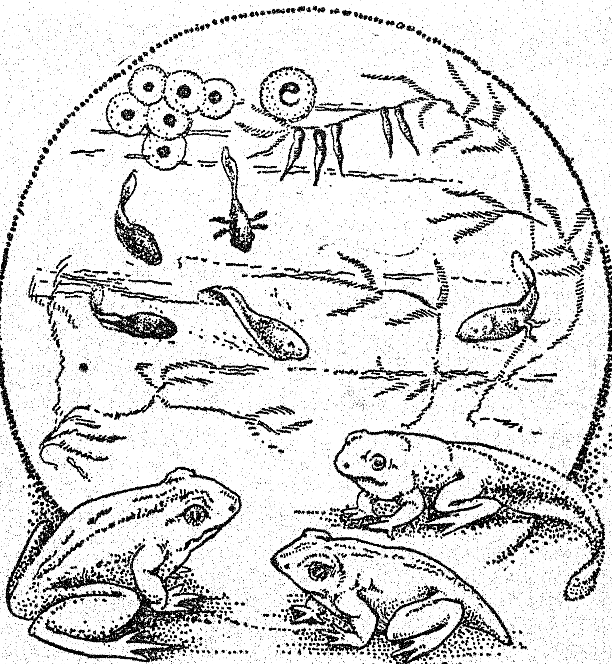


Figure 22. Stages in the life cycle of the frog.

grow legs, first the hind pair where the tail joins the body, and later a front pair close to the head. During this time the tail is gradually being absorbed by the blood corpuscles that circulate through it. By means of the blood this material is turned over to the growing animal very much

as though he had eaten his own tail and digested it. The tail finally disappears entirely.

The inside changes are even more wonderful. The intestine, coiled like a watch spring, in which he digested vegetable food, becomes more straight, and becomes suited to animal food. The gills by which he got oxygen from the water gradually disappear, while deeper in his body is developing a pair of lungs into which he takes air through the nostrils. The blood vessels from the heart change so they can take proper care of this new kind of supply of oxygen. The frog doesn't take a vacation during this time. He has to capture food, and must keep his wits about him every minute so that some otner animal will not capture him. It is really a remarkable performance. It is as though a gasoline launch were gradually changed into an electric automobile, which could run either on land or in water, and during the whole of the transformation was a perfectly usable vehicle!

CHAPTER SEVENTEEN.

THE BIRDS.

1. When the Chicken Leaves the Egg. When a young chicken, or other bird, comes out of the egg, we are disposed to take him as he is and ask no questions about his past. At this time the young bird is enough like its parents for us to recognize it as a bird. To be sure, it makes some changes after it hatches, but it has all the organs of the adult, and it lives in the same general way that it does when it grows up. It is not very hard to imagine that a young chick plus proper food should in due time become a laying hen or a fighting cock. After hatching it passes through no such changes as we saw in the passage of the tadpole into the frog.

But the events back of this appearance of the bird from the egg make a most remarkable chapter in its history. Indeed many of the things that happen within the shell are not unlike the passage of the tadpole into the frog.

2. The Character of the Egg. The egg of the bird has a limy shell about it, and inside that is a tough membrane. Just within this membrane is the sticky "white" of the egg. Not one of these things is a part of the real egg. All of them were added after the egg was formed. The real egg is the part we call the yellow, or yolk.

Most of us have seen in the body of an old hen, being prepared for the table, the ovary with a number of yolks of different sizes, like little potatoes around a potato plant. These are of different ages, and one or two may be

about as large as the yolk in an ordinary egg. The larger ones are about ready to escape from the ovary and start to the outside world. When the egg (or yolk) is ready it passes from the ovary into the body cavity and enters the large opening of the **oviduct,** or egg tube, which carries it to the outside world. As it goes down the oviduct the wall of this tube secretes the albumen (white) all round the yolk. It goes gradually twisting down the

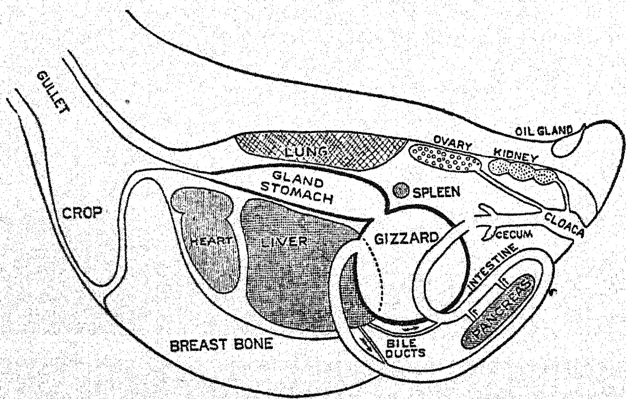


Figure 23. Diagram of internal anatomy of pigeon. *From Colton's Descriptive Zoology.*

oviduct and finally comes to rest at a point where the shells are formed around it. Soon afterward the hen lays the egg.

3. Fertilization and Development. It must be clear that fertilization of an egg like this could not take place as it does in the frog. A sperm could not possibly work its way through the shell or through the sticky albumen. If the egg is to be fertilized, it is necessary for the sperm to unite with it early in its course through the oviduct, and before any of these materials are added. This means that the sperm cells must be inserted in the outer opening

of the tube and then ascend to the upper and inner part of it where the egg enters. This is just what happens. When the male and female bird mate, or copulate, the sperms are discharged in large numbers into the **cloaca,** or opening of the digestive tract, from which they make their way upward into the oviduct. Only one is necessary to fertilize each egg. The others die.

After fertilization it requires the fertilized egg, or embryo, several hours to pass down the oviduct, get its shells, and escape. During this time the nucleus, or protoplasm, of the young embryo divides a number of times, so that when it is laid it is not really an egg. It is a young chicken of, perhaps, several hundred cells. It does not at this time look the least like a chicken. It is just a little round spot which one sees on top of the yolk if an egg is broken and put in a saucer.

4. Development and Hatching. Such an egg as this, which is really a young chicken, will keep its life for a while if the egg is put aside, but not for very long. If it is left long the young chick dies, and the egg begins to decompose. If, however, the egg when first laid is put in a constant, warm temperature, the cell division continues, and the young chick which was at first just a little spot of cells on one side of the yolk, grows all round the yolk. It develops a heart, and blood vessels that run out over the yolk and collect food from it and bring this back to the growing parts. Thus when the egg is warmed by the hen's body in the nest, or by an incubator, the same sort of development takes place that we studied in the frog. Only in this case there is so much food in the egg that all the steps similar to those which occur in the frog after it hatches take place in the chick **within the egg.** In other words, the frog has further to go after it hatches than the bird has The bird goes further in its development on the strength of the food which the mother stores in the egg.

5. The Changes at Hatching. There are some important

changes for the chick at the moment of hatching. Up to this time the oxygen, which is necessary for all life, passes through the shell and finds its way into the blood directly by means of some special embryonic membranes. When the chick breaks the shell these membranes dry up and all the oxygen goes into the lungs in the ordinary way. Before hatching all the food has been taken by the blood from the substances in the egg. Almost immediately after hatching the chick begins to practice its instincts for pecking at food, and soon gets to using its digestive tract. Other vital activities follow and the young chick soon performs all the important functions in just the same way the adult does.

6. The Sexes in Birds. The males and females are always distinct in birds. That is to say, one individual produces sperms and another eggs. Furthermore, the two parents, when adult, are usually quite unlike in appearance, instincts, and behavior. The chicken is a good illustration here, though not better than many other birds. The rooster is larger, more brilliantly colored, more aggressive, more noisy, and has certain structures which the hen either does not have, or not in such degree, as spurs for fighting, comb, wattles, etc. In many birds the male has better developed powers of song. It is thought that many of these qualities in which male and female birds differ are adaptations that enable each the better to meet the work which it must do. For example, the spurs of the cock, his greater size, and his aggressiveness seem to fit in with the fact that in some measure he takes the lead and protects the flock that surrounds him.

Birds have power to reproduce only by the union of sperms and eggs.

CHAPTER EIGHTEEN.

MAMMALS AND MAN.

1. The Special Development of Mammals. The specialization of mammals, as compared with other vertebrates, is chiefly in connection with reproduction and care of young. There is no group in which these functions are more successfully cared for than in mammals. No group has developed higher, finer, more successful instincts and practises. The name mammals comes from the mammary or milk glands by which the young are nourished after birth. The developing embryo is carried for a considerable period of its early development in an internal organ of the mother. Here it is nourished and protected from the unfavorable conditions outside. It is largely because of these facts, and the instincts and habits that grow up about them, whereby the bonds between the young and the parents are strengthened, that the mammals are so successful and seem to be at the head of the animal kingdom.

2. Man's Place with the Mammals. As an animal, man is not different from the higher mammals in any very important particulars. He has all the characters of the mammals and some particular ones beside. His reproduction is identical with theirs in all important respects. He cares for his young somewhat better than the others, and educates them longer, gives them a better home, and more sympathy, but the beginnings of everything man does for his children are found in what other mammals do for theirs.

3. The Gametes in Mammals. As in birds, there is no reproduction in mammals except by the formation of eggs and sperms. The sexes are always separate. The female reproduces by small eggs, much smaller even than those of the frog. Sperm cells are produced by the males in testes just as in frogs and birds.

The mammals are like the birds in that the eggs are fertilized within the body of the mother. This is not because of a shell about the egg as in the case of birds. It is rather because the embryo when fertilized is going to remain in the body of the female and there develop. It is incubated **within the mother instead of in a nest.** For this reason the sperms must be inserted into the special female organ, the vagina, by a special act of mating called copulation. From the vagina the sperms ascend and meet the eggs as they come down from the ovaries. The meeting place of sperm and egg is usually the organ in which the young are retained during early development. This organ is the **uterus,** or womb. It is a special organ formed by a great enlargement of the oviducts or tubes that lead from the ovaries to the outside.

Fertilization itself differs in no way from that studied in the lower plants and animals.

4. Early Development of the Embryo. After fertilization the fertilized egg (embryo) divides into two cells, then into four, eight, sixteen, etc., just as in other animals. By steps similar to those studied, the embryos become differentiated into nerve, and muscle, and cartilage and the other tissues. These steps need not be followed again. The point which makes the mammal embryo so peculiar and interesting is this: there is little food in the egg, hence it cannot live as long as the frog's egg or the hen's, on the strength of its own food. So, very soon after fertilization the embryo attaches itself by root-like outgrowths to the tender walls of the uterus. Through these connections it takes up nourishment from the blood of the

mother. Thus it grows, literally a parasite on the mother just as the sporophyte of the moss is a parasite on the gametophyte.

As the heart and blood vessels of the young mammal develop, the latter run out to these connections with the mother just as those of the chick did over the foodstuff in the egg. Oxygen as well as food is thus received from the blood of the mother, and the carbon dioxide and other wastes are returned to it.

This internal development continues for very different lengths of time in different animals. In one of the groups of mammals, the **marsupials,** which includes the opossum and kangaroo, the young are carried only for a short time. They are born in a very immature condition. They are then placed in an outside pouch which contains the milk glands. Here the young remain until they are mature enough to take some care of themselves. In the higher mammals, the period within the uterus varies from a few days to a year or more. For the large mammals it is usually a little less than a year. In these the development at birth is greater than it is in the marsupials.

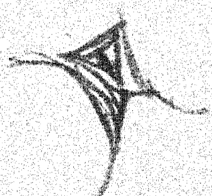
5. Birth and its Changes. Birth in mammals may be said to correspond to hatching in the birds. The young mammal passes through all its embryonic stages in the uterus and has all its principal organs ready for use when born. While it is living one kind of life (that within the mother) it is being made ready for a very different one. The change in birth is like that in hatching, a very sudden one. The change of life in the tadpole on the other hand comes very gradually.

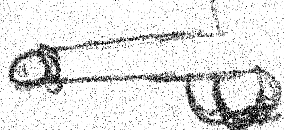
Before birth the young are surrounded by the body of the mother and have a constant temperature. At birth they are brought into a very much colder and more changeable temperature. Before birth all the food and oxygen are taken up by the blood from the mother's blood. At birth this supply ceases, and the lungs for the first

time are used and oxygen taken through them. Similarly the digestive tract has been developed merely for the use it was going to serve, not for any value it had before birth. One can readily see that birth is not in any sense the beginning of life. It is merely a change from one kind of life on the part of the embryo to another kind. It is similar to that which the toad makes when it passes from living and breathing in water to living in the air.

6. Care after Birth. It must not be thought that the mammal young are, or ought to be, completely independent at birth. Just as in birds, there is a period in which the young demand a great deal of care from the parent. This is accomplished in many ways, but the particular form of care in which we are interested is that peculiar to mammals and which gives them their name. This is by means of the secretion known as milk. It is produced by skin glands which have become highly modified and often greatly enlarged. It consists of water, of salts from the blood, of a form of sugar, of considerable oil which in fine particles gives the milk its whiteness, and of certain proteins. It is thus a complete food for the young animal. From the point of view of successful reproduction, milk makes it possible for more of the young to live than could possibly come to maturity without it. Carrying the young in the body and furnishing them with a complete food when first born are two most wonderful inventions, so to speak. They go far toward insuring success to the group of animals that use them.

All that has been said about the reproduction and development of mammals applies to man.





CHAPTER NINETEEN.

THE YOUNG OF THE HIGHER PLANTS.

1. Vegetative Reproduction among Plants. Already we have referred to the fact that many plants produce new plants by buds, or tubers, or roots, or runners, and even by leaves. The higher plants differ very much in respect to this rough and ready kind of multiplication. Some plants have none of these methods, others may use two or three of them.

2. The Older Idea of Reproduction in Plants. Until recent years the reproduction of plants by seeds would have been described as follows:

"The seed contains an embryo. When the seed germinates, the embryo breaks through and develops roots and leaves that enable it to get its own nourishment. It now grows until it becomes mature. The mature plant forms flowers which are its reproductive organs. Each complete flower, in addition to the protective and colored parts (sepals and petals), contains both male and female organs. The stamens are male organs and the pistils are female organs. The pollen, arising from the stamen, is the male cell and corresponds to the sperm, but has in itself no power of motion. The ovary develops an egg cell deep in each ovule. When the pollen is carried to the stigma and the pollen tube grows down into the ovule and unites with the egg, the male cell is fertilizing the female cell."

This is not the correct interpretation of sex reproduction in plants, although it is the way in which many people

understand it. There is enough of fact and enough of fiction in this interpretation to make it necessary to give the process in a little more detail.

3. The Modern View of Reproduction in Flowering Plants. Botanists now describe this process as follows:

The plant develops from the embryo in the seed and presently produces flowers. Flowers are really clusters of special leaves; sepals, petals, stamens, and pistils being each a set of these special leaves about the end of a stem. The stamens and pistils are like the leaves of the fern plant in that they bear spores. The other leaves do not. The stamen is not a male organ; it is a spore-bearing leaf. The whole plant is therefore a sporophyte. The pollen is not a male cell; it is, at first, just a spore. The pistil is not a female organ; it is also a spore-bearing leaf, and deep in each ovule at least one large spore is borne. The spores (pollen) borne by the stamens are smaller spores than those borne by the pistil. The spores in the stamen escape; those in the pistil are deep in the tissues and can not escape. When the pollen spore is carried to the pistil it germinates by producing a tube which grows into the ovary. The nucleus of the pollen cell divides once

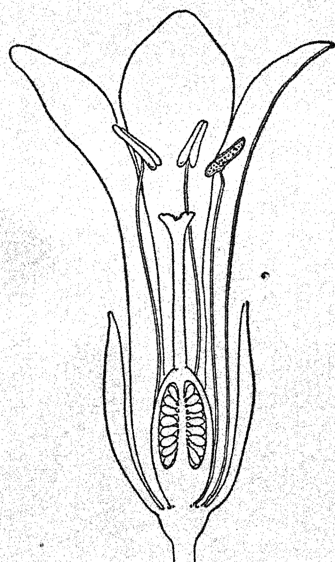


Figure 24. Diagram of lengthwise section through a complete flower. *From Coulter's Plant Life and Plant Uses.*

or twice, and two or more of these nuclei pass down the tube and reach the tissues in the ovary. In the meantime the nucleus of the large spore in the ovary has divided into eight or more nuclei, and one of these becomes the nucleus of an egg. The nuclei in the pollen tube escape and one of them unites with the egg nucleus. In this way fertilization takes place. Thus we see that pollen grains are not sperms, but nuclei in the pollen tube after the pollen has germinated are really the sperms. The egg is not formed directly by the growth of the ovary tissues, but by the division of the nuclei in the large spore which the ovary produced.

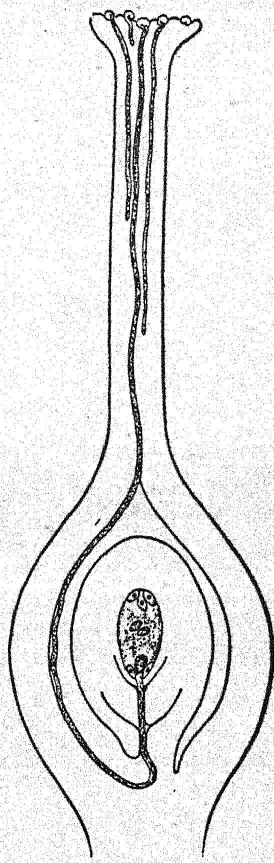


Figure 25. Diagrammatic view of a pistil, showing entering pollen tubes. One of them has reached the tissue which contains the egg, and fertilization is about to occur. *From Coulter's Plant Life and Plant Uses.*

4. What is the Real Difference Between the Old and New Views? In the old view we have just a straight, direct union of a male cell produced by a plant (such as an apple tree) with a female cell produced by the same apple blossom. In the new view we have the flower producing spores as in the fern, only in the flower we have two kinds of spores: a small spore pro-

duced in the stamen and escaping, and a large spore produced in the ovule, and **not** escaping. The small spore (pollen) grows into a small male plant (male gametophyte): the large spore in the ovule grows in its place inside the ovary in the pistil into a small female gametophyte. The small male gametophyte produces two sperms, one of which unites with the egg that is formed in the female gametophyte.

In other words, the old view thought of plants as reproducing by the sexual method merely, as in the higher animals. The new view states that seed-plants have an **alternation of generations** just as the fern has. It states that the seed plant has a generation that produces spores, and these in turn produce another generation that forms gametes. According to the old view the embryo in the acorn is the child of the oak tree. According to the new view it is the grandchild.

5. What are the Proofs that there is an Alternation of Generations in Seed Plants? It is not possible here to give all the facts that convince the botanist that the modern view is the right one, but there are two or three things that may make it seem reasonable even to a beginner. Everybody agrees that **a new generation starts when gametes unite.** So when the nucleus from the pollen tube unites with the nucleus of the egg cell, and this fertilized cell begins to grow, we are sure we have a new plant started. We can trace the growth of this plant at all stages into the seed, and through germination, and on to maturity. Furthermore, when these cells unite we have the 2X chromosomes that we found in the sporophyte of the moss and the fern; and this 2X condition of the nucleus continues all through the life of the flowering plant.

In the second place, when the pollen is formed, it is formed very much like the spores in the fern. The chromosomes are reduced to the X stage as they are in the spore-formation of ferns. The pollen furthermore

germinates as a spore does and its nucleus divides to form the nucleus that fertilizes the egg. A real male cell never **germinates or divides** so far as we know. The **pollen** does not unite with the egg; one of the cells descended from the pollen unites with the egg. In a similar way the large cell first formed in the ovule, which has been called the large spore (megaspore), is not itself fertilized. It is not an egg. It divides several times, and one of its descendants becomes an egg.

Finally, while there are many differences between the alternation of generations in the fern and the alternation in the higher plants, we can find conditions in plants lying between (connecting links) that prove to us that the higher seed plants have a clear alternation between sporophyte and gametophyte, and show that this alternation in the seed plants is evolved from the alternation in the lower plants.

6. Changes from Fern to Flowering Plant. The following are the chief changes that would have to come to the fern to make a flowering plant out of it:

1. Some of the leaves only would bear spores while the others would give up this work altogether. We find this condition among some ferns.

2. There would need to be produced two kinds of spores, small and large; the small producing a male gametophyte and the large a female gametophyte. This also is found among some of the allies of the ferns.

3. The size of the gametophyte must be very much smaller than we find in the common fern. Indeed the gametophyte in the seed plant is little larger than the spore. This is true also of some of the fern plants.

4. The large spores would not escape from the leaf that produces them, but would germinate and the resulting plants would live parasitically on the tissues of the sporophyte.

5. Because the seed plants are mostly aerial and the

female cell is formed deep in the tissues of the sporophyte, a delicate motile sperm cell could not reach the egg. Hence the small spore in germinating produces a tube that penetrates the tissues and allows the sperms to pass down through it. Sperms of ferns and mosses have cilia, and are active in motion. The sperms of seed plants evidently have no need for activity of motion, yet we find that the sperms of some of the lower seed plants have cilia, which strongly suggests that their ancestors had need for ciliated and actively moving sperms.

CHAPTER TWENTY.

RELATIONS OF PARENTS AND OFFSPRING.

1. Review. In Chapter Eight we studied these relations in some of the lower plants and animals. We found that reproduction is always a sacrifice on the part of the parent; that this sacrifice is necessary to keep the species going; that the parent is completely destroyed in the lowest forms of reproduction, as fission; and that the parent can economize by giving a smaller part of itself to each offspring. Thus we saw a reduction in the amount of substance which went into each offspring.

2. What Parents Must Do. Just the same problems confront the parent in the higher forms as were discovered in the lower. Two parents must, on the average, bring to maturity two offspring during their own life time in order to keep the race where it now is. The problem of parents is to hit upon the best way to do this. It is for the good of the race that the parent shall not be used up in this sacrifice until enough offspring have been produced to allow two to survive the disasters that confront them. On the other hand, the parent must sacrifice enough matter and energy in reproduction to insure the species.

3. Condition in Higher Organisms. In the higher plants and animals we have found two methods of reproduction that are peculiarly prevalent: reproduction by spores, and reproduction by gametes. In both of these methods the offspring consists of a single cell, whereas the adult may include millions of cells. Thus the ratio of the offspring to

the parent is in volume very small. This, as we have seen, is much more economical to the parent, but it puts a long period of immaturity and dangers before the offspring.

In this situation the organism has two possible ways of increasing the chances of enough offspring coming to maturity. In the first place, it may produce a much larger number of the single-celled offspring in order to overcome the great fatality. Or, it may give especial care and protection to the offspring and thus diminish the fatalities. Indeed it may do both. **It is in this care of offspring after they are produced that the higher plants and animals excel.**

4. Parental Care of Offspring. You must not jump to the conclusion that the care of young by parents is necessarily conscious and deliberate. In man it is partly so, but for the most part it is instinctive and unconscious. It is none the less valuable on that account. The care of offspring in some way or other is one of the most common things in nature. That it is a good arrangement is shown both by the wide-spread occurrence and by the kind of success that comes to those species in which it is best developed. Remember also that parental care means sacrifice just as reproduction does. It is another kind of sacrifice.

5. Different Forms of Parental Care. The ways in which parents may help their immature young are almost as varied as are the plants and animals themselves. There are, however, certain classes of caretaking that are conspicuous because they are found so often. Thus we note the storing up of extra food in the eggs, as in reptiles and birds. Eggs may be laid where an abundance of food will be found as soon as they are hatched, as in flies, beetles, and many other insects. Parents may give aid in hatching, by carrying the eggs around attached to the body, as in lobsters, or by incubation, as in birds, or by carrying the eggs and young in the body during early development, as in the higher

plants, some sharks, some snakes, and all the mammals with a few exceptions. Special protection may be furnished the young after hatching, as by the coats of seeds, and by active efforts, as in many of the higher animals. Birds capture food for their young, and the mammals secrete it in the form of milk. Special education of the young through imitation and other faculties is seen in birds and many mammals.

It is not our purpose to dwell at length on the different forms which the care of parents for offspring may take. But it is our purpose to make clear that this kind of care **after** reproduction makes it possible to diminish the original cost to the parent in substance. When bacteria divide into two half-sized individuals, the daughter cells have as much substance of the parent as is possible, but there is no parent left to give them any care. This is successful. No group is more successful on its plane of living than the bacteria. At the other extreme we have man, in whom the embryo has very little endowment in the egg itself, but has the maximum of parental care, in that it is carried in the body, is supplied with food, and receives definite protection and education for a long period after birth. Men can keep the species up, that is, each family can bring two to maturity on the average, with a birth rate of three or four during the generation.

6. Effects of Parental Care in Higher Forms. There are several things, especially important in human life, that grow out of this increasing care of parents for the young after hatching or birth. These things have great influence on the species and on the relations of individuals.

In the first place, **the period of infancy and helplessness grows longer and longer as we ascend the scale of life.** The higher the parent physically and mentally, the more difference there is between the offspring and the mature parent; the further the offspring have to go in their development. Thus there is the more need for parental

care, and the more opportunity for education. This makes it possible for the young to progress faster and more safely than if they had to learn every thing through their own experiences.

Secondly, **the care of young tends to hold the parents together.** This is true during the breeding season at least, and thus something of a home or social life is developed. We see this among ants, bees, birds, and the higher mammals. There is no doubt that this adds to the efficiency of a species.

In the third place, the long period of dependence of the young on the parents tends **to develop in the parents themselves the qualities that make better parents of them.** Anything that increases their sympathy and disposition to make sacrifices for the offspring will react on the welfare of the offspring and for the good of the species. It is possible that the good points of parents themselves have thus been increased from generation to generation.

The highest human sentiments cluster about marriage, parenthood, and care of young, and these play a most important part in the progress of mankind socially and morally. Indeed all social progress is closely related to these fundamental capacities and tendencies in connection with reproduction and care of young.

CHAPTER TWENTY-ONE.

REPRODUCTIVE INSTINCTS.

1. Introduction. Thus far we have been discussing reproduction chiefly as a process whereby individuals increase the number of species. Reproduction thus viewed seems to be a result that can be had by a number of different kinds of machinery, much as we may cultivate corn with a crooked stick, or with a hoe, a single plow, or an up-to-date cultivator. The methods differ in efficiency, but all lead to the same result. The real meaning of the process is very much the same whatever method is used.

2. Tendencies in Life. It does not explain the fact of reproduction, however, merely to say that the species would die out if the individuals do not reproduce. What difference does it make to the individual if the species does die out? We cannot imagine that the individual plant or animal is conscious of this fact, or that it is directly influenced in its behavior by this fact. Deep within the living thing is the **tendency** to grow, and equally the **tendency** to divide. We have no real explanation of how it comes to be, but we do know that as we ascend the scale of life the process of reproduction becomes more and more complex. There come also to be various tendencies in plants and animals, associated with reproduction, that we describe as habits or instincts. Some of these are peculiarly important and interesting, and help make reproduction more efficient.

3. The Meaning of Instincts. If an individual learns to

do a certain thing and does it so often as to come to do it readily and without conscious attention we say it has become a **habit.** If an individual inherits a tendency to do a thing a certain way, and this tendency thus belongs to the whole species we say it is an **instinct.** Instincts are thus more deeply ingrained into life than habits are. They are not "learned."

The great vital acts, like feeding, adapting one's self to climatic conditions, and mating and reproducing are surrounded by instincts such as have been described. If an infant is hungry, it instinctively cries and seeks for its food. If a particle of food is placed on the back of its tongue it automatically and instinctively swallows. It is very certain that food-getting, adjustment to cold, mating, and reproduction could not possibly take place in plants and animals with any such precision as we have seen, if it were not for these deep instincts.

4. Some of the Instincts Connected with Reproduction. The instincts that tend to make reproduction certain and efficient are of three classes:

(1) The instinct of reproduction itself, which in a purely unconscious way prompts the animal, when it begins to approach maturity, to form the reproductive cells. These are the deepest of all these instincts. Indeed they are so deep that we know very little about just how they work.

(2) The instincts connected with mating, which bring the sex cells together so that they may unite.

(3) The instincts of caring for the offspring until it is able to care for itself.

5. The Sex Instincts and Impulses. When minute gametes are produced it is easy to see that it is something of a problem to bring them together and cause them to unite. The simplest instinct connected with mating is the attraction exerted by one gamete on the other. When the female gamete secretes substance in the water, the male

gamete is so sensitive to it that it at once responds, very much as a young animal swallows when food is in its mouth. There is here something inherited in the nature of the sperm that impels it toward the egg.

When one gamete comes to be formed by one parent and the other gamete by a wholly different one, it is not enough that the gametes attract one another. They are so separated that neither can influence the other until they are brought together. In order to bring the gametes together, the parents must attract one another. Out of this condition of different parents, carrying different kinds of cells that must be brought together, we have arising the selfish sex desires that lead to the attraction and mating of the parents. These impulses are evidently felt by many of the lower animals as well as by the higher. They are usually stronger in the males than in the females, and cause the males to seek out the females. They are among the most powerful instincts known among animals, and insure that the gametes will be brought together.

In connection with this purely mating instinct, we find a number of others that are only indirectly connected with mating. Such are the singing and acting instincts of the male birds at the mating season; the actions of spiders at the same period; the fierce fighting instincts of some of the larger male mammals and of some birds; the instinct of flight in the mating of the queen bee. Many other similar phenomena might be mentioned.

6. Relation of the Sex Instincts to the Reproductive Instincts. It has been repeated frequently that the whole of reproduction is a process of sacrifice. It looks toward the species. The instincts that lead to it may be fairly described as unselfish, without implying that the organism is conscious of it or deserves any credit for it. On the other hand, the instincts of sex **point solely to satisfying selfish desires and appetites.** They are like hunger and thirst in that they involve satisfaction rather than sacrifice. They are just as selfish as eating.

7. The Tendency in Man. In lower animals and plants there is no special tendency to abuse or over-use the sex instincts. In man, on the contrary, just because we can remember and think and anticipate gratification, men do give way to these desires and impulses in ways that animals do not. An animal that is not deprived of food is not likely to overeat, though it may give nearly its whole time to eating; so it is with its sex gratification. Man, however, because he can dwell on the pleasures of food, can talk about the things he eats, and can do various things to make our food more pleasant, is constantly falling into over-indulgence in the matter of eating. His **continued consciousness and imagination** of the pleasure is a temptation to him. This same tendency in man is seen in gratifying the sex impulses, and some most serious dangers to our society and to our morals and our civilization are connected with sex.

8. The Need of Education. It has long been the custom to say little to young people about the facts of sex and reproduction. It has been felt that knowledge of these matters might make more of wrong doing, but human sentiment is changing with respect to this. It is coming to be felt that young people will be helped and not harmed by knowing the wonderful facts of reproduction.

You should know that the sex impulses are natural and, if not wrongly used, build us up in all the qualities which each sex admires in the other. But you should also clearly understand that these impulses are selfish, and **must be self-controlled.** They are in danger of leading us into wrong that is likely to destroy health and morals, respect for each other, self-respect, and happiness. It is certainly true that instincts and impulses that have all these possibilities of both good and evil can be better guided and controlled if we know about them than if we are ignorant. Nature has shifted the responsibility to us.

With his powers of reasoning and of imagination, there

has come to man **responsibility for his own guidance.** It is these powers of reasoning and imagination which tempt him to indulgences which are destructive. It must be the same powers of reasoning and imagination which will reveal to him that he **must** be his own master and control his instincts. By reason he must judge which of his feelings are good and which are bad, and by his will power he must control his acts. Otherwise he travels a path which leads to destruction.

It is surely true that instincts which have such wonderful power for good or evil can be better controlled and guided if we understand them than if we are ignorant of their meaning. You have an instinct for what is right as well as for what is wrong. Your happiness and real success in life can be won only by standing firmly by what you know to be right.

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CHAPTER TWENTY-TWO.

HOMES AND HOME MAKING.

1. Homes and Homes. There are all sorts of homes among animals, and it is necessary for us to try to define what we mean by a home. Many animals burrow in the ground or in wood or even in stone, and thus form a den into which they may retreat as a protection. This is a very simple kind of home, if we can call it a home at all. The burrows of the earthworm or the mole or the burrowing beetles illustrate this type of home. Some animals make or find places in which they store food for winter. We see this in squirrels, ants, etc. The desire for protection and for storing of food is thus the motive for home-making of a simple sort.

There is, however, another factor, which may be found alongside these, that is more important than both of these in insuring the making of homes. This is the care and rearing of offspring. Many animals seek or prepare a specially protected place in which they rear their brood. Indeed so important is this factor that we can scarcely give the name of home in those cases where young are not cared for.

2. Homes for the Rearing of Offspring. We have seen that increasing care for offspring tends to hold together the parents while the young are immature. This is not always true. Very often one sex is left alone to care for the young, but usually where such instinct exists at all, both father and mother give some attention to the young.

This common tie inevitably leads to closer and more permanent relations between the parents. We see this in many birds. In most of the song birds those of a pair remain faithful during the whole season; indeed in some it seems that they are faithful through several years, or even through life. The nest of such birds is a real, though temporary, home in the very strongest sense of the word.

In those animals that have homes in which the young are reared it is true, also, that there is a better opportunity for the growth of the sympathetic instincts between parents and offspring. The home becomes a center of attraction. It is easy to see, therefore, that home making for care of offspring is a great step in the development of social instincts as against the purely selfish instincts. Many illustrations might be mentioned, but it is among the birds and man that we find this idea developed at its best. In many species of ants and bees we have most elaborate homes, but these are the homes of societies or colonies rather than of families. Such social insects illustrate a very striking form of home, therefore. The termites, or white ants, most of the wasps, some of the spiders, and some of the burrowing mammals as moles, rodents, etc., extend the list of those animals that make homes.

3. The Home Idea Among Men. The earliest traces we have of human homes on the earth are caves, which man found and adapted to his needs. Later he made excavations of his own in the hillsides, as did the cliff dwellers of the western United States. Thatched cabins and other primitive forms of structure have been known in all parts of the world. The physical structure of the home, however, is not an essential. It may be a cave or a tree or a hut or a palace—the biological facts underlying it are the same. These facts are—protection from the elements, and from wild beasts; defense from other men; a place to keep food and other essential property; a

place for sleep and rest and for companionship with mates; conditions suitable for the protection and rearing of the children.

From the viewpoint of these studies we are chiefly interested in the home as one of the factors in human mating and reproduction. This long period of helplessness in the human child makes it essential that the parents remain together and work more or less as a unit in the task of care and education. As society improves and the child needs to know more in order to succeed, this need becomes still more real.

The increase in efficiency in homes makes it unnecessary to produce so many offspring, since the better they are cared for in the dangerous period of infancy, the more will survive. Furthermore, those that do survive profit in the effectiveness of their own life by the improved life and attention of the parents.

4. Development of Marriage. The various kinds of relations that have existed between men and women in what we know of human history are closely related to this matter of homes. The mother who bears the children and nourishes them in infancy is naturally the very center of the home. The parental instinct is proverbially strong in her. Primitive man resorted often to violence to secure a woman for his home. She was kept in a sort of slavery or serfdom. She bore the children and did much of the work for their support. As time went on, all sorts of experiments in sex relationship were tried by the human race, depending on the supply of food and on the social and moral advancement of the people. For example, the race has tried several husbands for one wife (polyandry), several wives for one husband (polygamy), one husband and one wife (monogamy), capture marriages, marriage by consent of parents, marriage by consent of mates, political marriages, religious marriages, romantic or love marriages.

A great many biological as well as social and moral considerations point to the permanent monogamous marriage as the most successful possible solution of this relation, from the point of view of producing and protecting and educating offspring. This test is the real final test of its rightness. True permanent homes are essential to proper rearing and development of children. Real homes cannot be developed other than by full devotion of both parents to the task and to each other.

5. The Ideals of the Human Home. It is clear that a real home means a permanent, faithful devotion of the parents to the task of producing and rearing children. It means that each must deserve and have the complete confidence of the other. Such close relations demand confidence. The welfare of the children equally demands it. It is not enough that the mother should be faithful and pure. It is just as bad and vicious for a man to be unfaithful to this ideal of the home as it is for the mother to be. Unless both are faithful, it is not possible to raise children in an atmosphere of truth and social and moral health.

To get right homes it is not enough that parents merely be true to their home and to one another; they must educate their children in the same ideals. One day these children will be making homes of their own and it is very essential that pure homes continue in the next and later generations. Young people who are not pure and clean before marriage are not true to this ideal of a home, for neither a man nor a woman who before marriage indulges in sexual intercourse can be an honest and perfect unit in a home. This is condemned by our history, by our laws, by morals, by religion, and by science.

6. Chivalry in Man. Men as a whole have not taken a manly position in this matter of sex purity. Men have said: "We insist that the woman we marry shall be pure and clean; but it is not so bad for a man to be impure as

for a woman to be. We, therefore, will allow ourselves more freedom than we will allow to our wives and mothers and sisters."

In the olden days it was the ambition of the real knight to use every opportunity to befriend and aid and protect the weak. The good old word **chivalry** has come down to us from those times. There is no boy with the instincts of a man who would not protect his sister or his sweetheart from a licentious man. Any knightly man would die to defend the honor of any woman who, in any way, looks to him for protection. Does not this same spirit say to us as young men that we in our turn will protect every woman just as we would our mother or sister, even from ourselves? Is it not a part of the honor of every boy in school to protect the honor of every girl in school just as though she were his own sister? Can we really be men and do any less?

The purity and fineness of the families of the next generation depend on the chivalry of the boys of today and the purity of the girls of today. The quality of the family life determines the whole social and moral structure of the nation.

CHAPTER TWENTY-THREE.

GROWING UP.

1. In the Simplest Forms. Thus far we have spoken about the process of reproduction and the work of the parents. There is another very interesting side to the matter. This is the growing up or development of the young individual into the form of the parent.

In the simplest forms this has been seen to be a rather easy thing. In the case of bacteria, or paramecium, when the parent divides, each of the progeny has to double its size. In the bacteria this requires only a half-hour or so under favorable conditions. In paramecium it takes a little longer. Where the parent differs from the offspring only in size the problem is merely one of growth.

2. How About the Higher Organisms? When we come to a higher plant or animal, in which there are numerous different kinds of organs in the adult, we see that the work of the embryo in growing up is very much complicated. The one-celled fertilized egg has in it absolutely none of the leaves and roots, or brain and muscles and bones which the parent organism has. The most marvelous thing of all to the biologist is that a cell with nothing of any of these tissues or organs in it, with only a little mass of protoplasm, can develop these complex structures. The wisest biologist has no final answer to this question, and yet every egg that develops answers the question in its own practical way. Of course the student sees that it is no answer to the question to say

that the egg **inherits** the power and the tendencies from its parents. This only gives a name to the process. Where and how do these powers and tendencies reside in the embryo?

Development is much more interesting and difficult in the higher animals and plants because it means a great deal more than merely growing. It means **becoming different.**

3. What is Development in Higher Forms? There are three important elements in this mysterious process, and while we cannot explain why it takes place by describing these steps, it does make the process seem somewhat clearer to us.

a. **Growth.** In the first place growth is important, as it was in the lowly forms. Indeed the larger plants and animals grow more in becoming mature than the simpler ones. Often the increase is a million-fold. The great redwoods of California, which are among our largest plants, and whales, which are about as large animals as have ever lived, arise from eggs that require the microscope to enable us to see them.

b. **Cell Division.** When a bacterium divides it makes two bacteria, and thus the individual is kept small. When the egg of a whale divides the daughter cells remain together and we have a two-celled whale embryo. These continue to divide, and since they continue to remain together the embryo comes to have more and more cells. This makes the organism complex. As these cells grow it becomes larger as well as more complex.

c. **Differentiation.** Growth and cell division are not easy to explain, but the most difficult thing about development is **differentiation.** This means that these cells, all derived from one parent cell, are not alike. They may seem to start alike, but great-grand-daughters of the same cell may give rise to

cells as different as nerve cells, skin cells, bone cells, blood cells, and many others.

The young of the higher plants and animals have a long, difficult, and wonderful road to travel before they come to be like their parents. It is "natural" for them to do it, and we fully expect it to happen, but it is a marvel, none the less.

4. Direct Development. The egg of no one of the higher organisms looks in the least like the parent. If we take the chick, for example, the egg when fertilized has no resemblance to the chicken. Yet when the chicken hatches, in twenty-one days, the young chicken looks very much like the adult. It still needs to grow, and to differentiate a few things, like feathers, etc., before it is just like the parent. Now if we go back in the egg to the eighteenth or nineteenth day it still looked like a chick, but a little less so. By studying it thus we can find that it came very gradually to take on its likeness to the parent. There are no sudden or sharp changes in its development. We call this sort of development direct. This is a very common method of development. It is found in mammals, in birds, in reptiles, in most fishes, and in many lower forms.

5. Metamorphosis. Not all animals, however, develop in this way. We have already seen in the frog that the thing that hatches out of the egg does not look at all like a frog. It must make more changes after hatching than the chick does. This tadpole, which looks more like a fish than like a frog, may grow as a tadpole and live an independent life for quite a period before it begins the changes that make it appear as a frog. We see it as three different things: egg, tadpole, and frog. This indirect development is called a **metamorphosis.** It differs from the direct development in this: in a metamorphosis the organism becomes like the adult by passing through one or more somewhat sharp or sudden changes or stages.

Between these points of sudden change there are periods during which there is little or no change but growth.

Some of the most beautiful illustrations of metamorphosis in the growing up of offspring are found in the insects. Very many of the insects undergo a profound and striking metamorphosis. In the moths and butterflies we have a story something like this:

(1) There is considerable food in the egg, and when it hatches the animal that comes out is a small worm-like object which we call a caterpillar (larva).

(2) This feeds on leaves and the like and grows, but remains a caterpillar for weeks or months, during which time it stores up a large quantity of food.

(3) At the close of this period the caterpillar becomes quiet and inactive, often secreting about itself a protecting case.

(4) In this cocoon the whole structure is gradually but profoundly changed within, though there is no difference in the outside appearance of the cocoon. Old organs are taken up by the blood and new ones, suitable to the mature life, are developed from the stored-up material. Wings, of which there was no trace in the larva, long legs instead of the poor, stumpy ones, and different eyes and mouth parts appear.

(5) When this has all happened the changed animal breaks from the cocoon in the adult form of the butterfly. In this form it reproduces by eggs and sperms, and mating takes place. Thus the cycle is complete.

6. Possible Advantages in Metamorphosis. Without doubt this round-about development has both its advantages and disadvantages to the species, but on the whole it looks as though it aids the process of successful reproduction more than it hurts it. The adult butterflies

are adapted to taking nectar from flowers. But their caterpillars, which are able to eat voraciously of the leaves of early spring, can get a much more successful and early start than the nectar-living adult could do. Furthermore, the adults of all such forms, flies, butterflies, beetles, etc., appear full grown. They could not grow except by moulting all the complex outside covering and

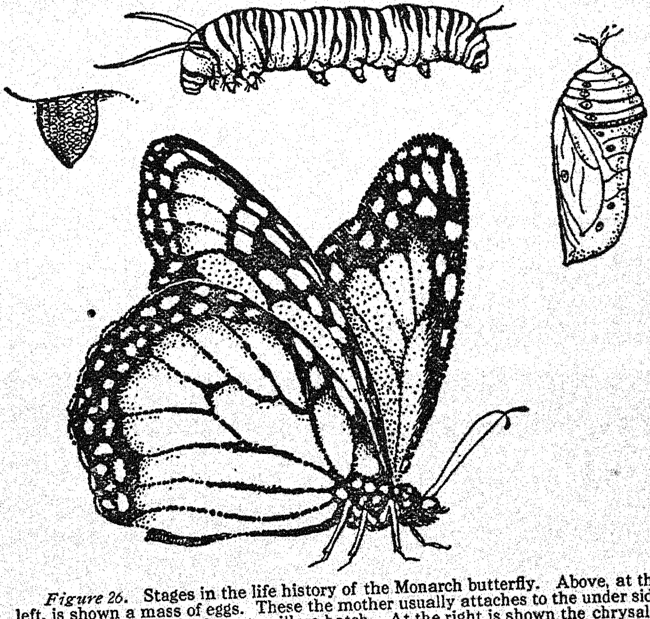

Figure 26. Stages in the life history of the Monarch butterfly. Above, at the left, is shown a mass of eggs. These the mother usually attaches to the under side of a leaf. From them the caterpillars hatch. At the right is shown the chrysalis or cocoon stage into which the adult caterpillar is transformed. From this chrysalis the butterfly emerges.

its organs. It is economy therefore for them to do their growing during the larval stages when they are simpler, and moulting is more easy. During this time they store up food enough to provide for the metamorphosis and the

making of all the adult parts. It is possible therefore to see that the metamorphosis may help make reproduction and individual development more successful. It makes the species rather more adjustable to the conditions of life.

CHAPTER TWENTY-FOUR.

THE RATE OF REPRODUCTION.

1. How Fast Must Organisms Propagate? Reproduction is to keep the species going. To accomplish this, as we have seen in former chapters, each pair must during their life bring to maturity at least two individuals. If they succeed in doing more than this the species increases in numbers; if they do less the species diminishes. On the average this is what each species does. Some may be gaining, but if they do, it is probably at the expense of other species. If a certain species of birds temporarily increases in a locality, the insects on which they feed will grow fewer there. On the other hand, if the birds should decrease the insects are likely to increase. The sum of life on the earth probably does not increase or decrease greatly from generation to generation. Man, at present, is increasing in numbers; and so, perhaps, are those plants and animals that he cultivates for his uses. But the forest trees, the wild plants, the song and game birds, and the larger wild animals are decreasing with his progress. Thus the total life remains about the same.

2. What Determines the Rate of Reproduction? How many offspring a plant or animal must produce that two may come to maturity will depend on the favorable or unfavorable conditions through which the young must go to reach maturity. Among these are the climatic conditions which favor or endanger the young, the amount of the food supply and the ease of getting it, and the

enemies that prey upon the young. But most of all it depends on the protection and care which the parents give to their eggs and their young. How many must be produced depends on such things as those just mentioned. How rapidly the parents must reproduce in order to bring forth this number will depend on the length of life of the parents.

In general, we may say that the rate of reproduction in any species that has stood the test of time and has proved successful does meet these conditions. Those that care for their young need not produce so many; those that have few enemies need not produce so many. But a pair must on the average produce rapidly enough, live long enough, and care for their offspring enough to bring two to maturity during their own life. Otherwise the species is doomed.

3. Some Examples of the Rate of Reproduction. While all organisms must thus produce more offspring than can hope to survive, they differ greatly in the actual number and in the rate of reproduction, because the other factors enter in so differently. For example, an organism that produces offspring which are large at birth, as the mammals, do not meet so many failures in bringing offspring to maturity as does a fern plant in which the reproductive body is a small and delicate spore. In general, there are two ways to increase the output of offspring: either by more frequent reproduction, or by increasing the number produced at a time, or by a combination of these.

a. **Bacteria.** Some species of bacteria may divide in half an hour. There are here only two offspring resulting, but the divisions may come so frequently that the bacteria multiply right up to the limit of their food in a short while. Because of poisons which they produce, and because the food at any one place soon gives out, they are unable to keep

up this rate long at a time. This rapidity of reproduction is very valuable to them, since the decaying food in which they thrive does not last very long. This power enables them to make the most of it. At this rate of increase, multiplying by two every half hour, in one day it would require twenty-eight figures to represent the individual bacteria resulting from one parent; the total would be two raised to the forty-eighth power.

b. **Paramecium.** Many of the one-celled animals live on the same kind of decaying material as bacteria. Some of them multiply at a rate nearly equal to that in bacteria. Most, however, are not so rapid. Paramecium, under favorable conditions, requires from twelve to thirty hours to divide and grow to maturity, but if its food held out and it could keep up this rate, it would require only a few weeks for the descendants of one paramecium to make a mass of protoplasm as big as the earth itself.

c. **Ferns.** The fern produces spores only once a year, but it produces millions at each season. If every spore out of a million should succeed in producing one mature fern plant, on the tenth year we would have 1,000,000 to the tenth power of new fern plants, to say nothing of all the old ones that lived over from previous years. A single fern plant could populate the earth with ferns alone in a few years.

d. **The House Fly.** Chancellor Jordan, of Leland Stanford University, says concerning the reproductive power of this pest: "If all the eggs of a common house fly should develop, and each of its progeny should find the food and temperature it needed, with no loss and no destruction, the people of a city in which this might happen could not get away soon enough to escape suffocation by a plague of

flies." With the rapid rate of reproduction in flies, one fly living all summer and producing a hundred or more of eggs, and one-half of her progeny being females, and coming to maturity in two weeks with the same powers, the swarm of flies centering in the city would overtake the fleeing man by sheer increase in numbers.

e. **Sparrows.** This is a bird rather more prolific than is usual. It breeds several times in one season, thus giving it the advantage over birds that nest only once. If we start the season with one pair and assume that they nest three times with four young at each nesting, and live five years, and that one-half are females, we can compute how many young there would be in ten years.

First year	2	12 young......	14
Second year	14	84 "	98
Third year	98	588 "	686
Fourth year	686	4116 "	4802
Fifth year	4802	28812 "	33614

And for the remaining five years each pair of these would produce as many as this first pair.

The student may be interested to find how many there would be in that time.

f. **Man.** Man produces much more slowly than any of the forms mentioned. Physically it would be possible for the healthy aboriginal man to reproduce about once in fifteen or eighteen months on an average. Or during the possible reproductive period of about thirty years one pair might produce, say, twenty offspring. Before the last one was produced, the oldest would be in its reproductive period, and thus the generations would overlap. As a matter of fact, we do not find families of this size. Marriages take place much later than the beginning of the reproductive period. The lack of strength

on the part of civilized women, the trouble and cost of rearing large families of children, the impossibility of rearing that many children wisely, and many other such considerations make it out of the question for human beings to reproduce up to the animal limit. Parents are not willing to make this much sacrifice, and it would not be wise if they did.

In new countries the average rate of increase in a single generation is between three and four children to the family. In old countries it is less, going down close to two children for each family, or in some countries a fraction less than two. This means gradual "race suicide," for a species can not be kept going if a pair brings less than a pair to maturity. Let us assume the higher number for the new country, or four children to each home. It is clear that at this rate each generation doubles the native population, and that if all the human beings lived, a very few generations would stock the earth up to its utmost limit of support. Some parts of the world, as the more populous parts of China, seem to have reached this condition now.

4. The Difference between the Rate of Reproduction and the Real Increase. Any one of the species of plants and animals would become a pest to us if they really multiplied at the high rates indicated as theoretically possible. The human race itself would soon find life intolerable if it reproduced to its full limit. But no species ever does. The winters and the drouths, starvation and internal weakness and disease, parasites and other enemies, —such things sweep off countless millions of all these species. It is a great struggle that goes on all the time among all the animals and plants that are born; for, in the long run, if a million are produced by two parents, only two can come to maturity. Many students think that it is out of this severe struggle that improvement has come

to plants and animals, for generally in the struggle the weakest are destroyed and those survive that for some reason or other are best adapted to all the important factors in the environment. The rate of reproduction in this way seems to be a matter of considerable value in determining progress.

CHAPTER TWENTY-FIVE.

CROSSING BREEDS.

1. Reproduction without Union. In reproduction such as fission in bacteria, budding in yeast, spore production in molds, and stolons, buds, grafts, or tubers in the higher plants, only one parent takes part in the formation of the new individual. In such cases the offspring is likely to be just like the single parent, because it is simply a portion of it. The single parent stamps its nature most strongly upon the offspring. It is frequently found that such stock gradually "runs down" if continued indefinitely, as in the case of Irish potatoes.

2. Union of Similar Gametes from the Same Parent. In cases where one kind of gamete is formed and the union takes place between cells that have the same parent, we have two nuclei taking part in the union, but they, having the same ancestry, are likely to be very similar. Nevertheless it appears that such a union as this tends to restore and strengthen the vitality of the embryo, as compared with organisms in which no union occurs. This is known as **self-fertilization.**

3. Union of Unlike Gametes from the Same Parent. We have seen that there are a good many hermaphrodite parents, in which one parent produces both eggs and sperm. The gametes are different, but the parent is one. This is found, for example, in tapeworms, in earthworms, in snails, in many plants. Doubtless self-fertilization occurs in many of these cases. It is similar to the self-

fertilization described in the preceding section, except that the gametes are distinctly different, are formed in different parts of the body, and their union introduces a little more possibility of newness and variety in the result.

4. Union of Dissimilar Gametes from Different Parents. While self-fertilization is possible in the case of some of the animals and plants which produce both kinds of gametes in the same parent, it is not the rule. In a form such as the earthworm or snail there are interesting adjustments that tend to prevent the sperm of one animal reaching and fertilizing the eggs of the same animal. In both of these cases, when copulation between two animals takes place, each animal transfers sperms to the other, and later the sperms are brought into union with eggs of other parentage. This is **cross-fertilization.** But the most common and sure kind of cross-fertilization in the animal kingdom is in the mating of parents which produce only one kind of gamete, exclusively male parents mating with exclusively female parents. In such case cross-fertilization is insured by making self-fertilization impossible. Separate maleness and femaleness is a device which **insures** cross-fertilization.

In the common seed-plants we have something quite similar. Most of the plants produce both kinds of spores in the same flower, and if the sperms produced by the pollen of a flower fertilize the eggs produced by the gametophytes in the ovary of the same flower, we might call it self-fertilization. We call it **self-pollination,** when the pollen of one flower acts on the pistil of the same flower. Self-pollination, however, seems to be the exception in higher plants rather than the rule. Just as in animals, there are many devices which prevent self-fertilization, and secure cross-fertilization. In plants there is a most wonderful series of adaptations tending to insure cross-pollination and to discourage self-pollination. Sometimes, as in the gametes in animals which have

separate sexes, a flower produces only pollen or only ovules. In other cases, as in the hermaphrodite animals, the two kinds of gametes in an individual flower do not ripen at the same time. All of these facts show that nature appears to favor cross-fertilization over self-fertilization.

5. Evidence from Experiment. Charles Darwin was the first to prove by actual experiment that cross-fertilization has, at least in some forms, advantages over self-fertilization. He took plants of one species and subjected them to the same general conditions. Some he forced to be self-pollinated if at all. He cross-pollinated others. As a result he found that those that were cross-pollinated set more seed, the seed weighed more, and the plants coming from them were more thrifty, on the average, than those produced by self-pollinated flowers. Other observers have found the same thing to be true. There is thus some advantage in crossing plants and animals, and the devices that we have seen that aid in crossing are expressions of this advantage. Some plants, however, seem to do quite as well with self-fertilization as with cross-fertilization.

6. Why is Cross-Fertilization Advantageous? This question is not easy to answer. We have not yet reached the place where the biologist can say just what is gained by mixing different strains in this way. It seems in some way related to this mingling of protoplasms, nuclei, and chromosomes, which have different history and composition. It is possible that new and different protoplasm coming in from the outside sperm is more stimulative to the egg than that from the same parent. It seems also that there is more chance for variety in the offspring when two different strains are mixed than when both cells are of the same strain.

From this last mentioned fact, whether or not this can be regarded as an advantage to the plant or animal species, we can readily see how it is of advantage to man. By crossing different apples, or peaches, or daisies, or cattle

and hogs, we get new strains. Sometimes these are of no value, sometimes they result in a mingling of the characters of both parents, and sometimes they give a result decidedly more perfect for our uses than either of the parents. Very much of the improvement in most of our cultivated animals and plants has been possible because of this mixing of breeds, together with the selection of what suits us best out of the results.

7. **The Limits of the Crossing.** We have seen that in mingling gametes there seems to be some advantage in having the gametes different, as in male and female parents. Where nature lays so much emphasis we have come to feel there must be something worth while. There is, however, a limit to the difference that is possible in gametes and in parents. If we select parents of different varieties, or particularly of different species, the offspring are quite certain to be different from either and often are not so good as either.

The following rules may help the reader appreciate this:

a. The more different the parents are the less likely their gametes are to unite. We may cross different species of lilies or different species of roses, but we cannot cross lilies with roses.

b. If fertilization succeeds, the more different the parents are, the more likely is the offspring to be imperfect. For example, we can cross the different varieties of horses readily enough. We can also cross the horse with the ass, and the result is the mule. The mule has qualities that make it a better animal for some human uses than either the horse or the ass. The mule, however, is entirely unable to breed. It cannot breed with either parent or with other mules. Its gametes seem to be imperfect. The horse and ass are of different, but related, species. The individual plants or animals which result from crossing different species are called **hybrids.** Hybrids are not all sterile, as is the mule.

In the human race the different varieties may cross. It seems that there may be some gain in the crossing of peoples nearly akin, as the English, German, French, etc., who are all branches of the Caucasian stock. The mixture of these different, but kindred, types often produces valuable results. There is, however, considerable evidence for the view that crossing the different races, as negroes with Indians, and negroes with whites, gives offspring more of the nature of hybrids; and while they are not necessarily infertile, they do not seem to have the vigor of the original stocks.

CHAPTER TWENTY-SIX.

THE END OF THE CIRCLE.

1. Our Circuit. We have been studying in these chapters one of the most wonderful of the many remarkable things about life. I wonder if I have made it so that you understand and appreciate it? I hope you may do both. We have seen how reproduction thwarts death. The parent would surely die sooner or later, but by dividing it saves the species and makes itself immortal. Gradually the process becomes perfected so the parents live longer side by side with their offspring.

We have seen how the increasing helplessness of the offspring makes the care of the parents more and more necessary, and how this in turn binds the mates together in the necessary task of caring for the young. This makes home possible, and develops sympathy and love and the finer qualities of sacrifice. The home relations become more and more important, until, in humans of the more advanced races, the home is looked upon as the very picture of what human society ought some day to become—a great family.

We have seen how family relations have built up in the best men and women a sense of respect and chivalry; how self-control is coming gradually to dominate the primitive animal sex-qualities; how the mental and spiritual appreciation of husband and wife for one another enlarge and enrich and refine their lives more than any single factor in all our conditions.

We must appreciate that anything that has belonged in this way to all life from the beginning, that has aided evolution so much, that has itself unfolded and improved so greatly, must be of great consequence in life.

It is because of this importance that this little book has been written. All of us know about reproduction; but often we do not stop to appreciate its beauty and importance in human development. It means much more in human life than anywhere among the animals.

In our study we have come around to ourselves. What does all this mean to us? This is the important thing. This is the end of all our circles.

2. Yourself.—I am thinking now especially of the young people who have been reading this little book. You are yourself still near the beginning of the wonderful cycle. It often makes us feel very small and unimportant when we study the great facts of nature, but it is inspiring to know that we ourselves are links in nature's endless chain. Of course each of us may **end** the chain, but if we normally perform our part in the cycle we are a part of this immortal stream of life. In continuing it we can add to it or subtract from it.

It is certainly a proper part of the ambition of every person, if one is normal in body and mind, to continue the good strains of inheritance that have come to him from ancestors. The fact that you are alive now is proof that the chain has been unbroken in your case for untold ages. In order to make **you**, there have been all these successions of individual, selfish upbuildings alternating with unselfish division and sacrifice of parents; all this crossing of strains; this manifold care of parents for offspring; the weeding out of misfits and the saving of fit; this marriage and building of homes; this developing of fine ideals of sympathy, devotion, and self-control—all these I say have been preserving and piling up and mixing the characteristics that your friends call **you**. In

one way or another you owe all your capacities and powers to this wonderful thing we have been reading about. If you are well and strong and normal, you have blessings you cannot properly measure.

We human beings have come pretty generally to feel that all such **blessings** and **powers** carry with them some **obligations**. We say of a young fellow who inherits from his parents property and a good name, and then through recklessness or incompetence squanders both, that he is a spendthrift—ungrateful and degenerate. What shall we say of boys and girls who are the "heirs of all the ages" in these finer human capacities, and who so barter them that they are not carried on to future generations? The whole race is robbed.

You then owe at least two things to society: (1) to give your best qualities a chance, and (2) to try to see that those who represent you in the next generation are the best possible, and have the best possible chance.

3. The Lower and Higher Qualities in Sex and Reproduction. In this discussion we have been trying to make clear that everything about reproduction is natural and with meaning. The divisions, the unions, the attractions, the impulses and desires, the satisfactions, the unselfish care given by parents, these are all a part of it, and are all sound and natural. You should know about them, and they must be kept natural. But all the natural things about reproduction and sex are not equally important to us as humans. The mental and spiritual and social states which we have developed in connection with these things are even more important to us than reproduction itself. **The worst thing that could happen to us is that we should be like the lower animals in reproducing.** We humans have all the lower qualities that the animals have, but we have developed the power of controlling and guiding these impulses of ours in loftier ways. Mating means to the lower animals certain instinctive desires and

gratifications. With us it means marriage, faithfulness to one another, the building of a home through sympathy, mutual unselfishness, and helplfulness. In the lower species the males often instinctively protect their females and young in an emergency. So do we, but in addition we feel that men should always protect and help and cherish children and women. We feel that a man who is not thus chivalrous is not quite a gentleman. In animals, the parents instinctively guard and feed their offspring, but with us the real mother and father do not only do this but help the children get their education, try to provide for their future, nurse and care for them when they are sick, sympathize with them in their difficulties, give their very lives for them in many ways. Courtship among the higher animals is an instinctive and passionate series of approaches culminating in mating. With us the earlier years of young manhood and womanhood are full of fine friendships and companionships in which our minds and spirits are developed in some of the finest ways we know, and the period of courtship itself is full of high ideals and devotions that make it one of the most charming times of our lives in and of itself.

So what I want you to feel is this—that because men and women control and guide and spiritualize these feelings and states that belong to reproduction and sex, we have built up around them a whole realm of human interest and a portion of our personality that inspires all good people more than the facts themselves. This is shown in our finest poetry and other forms of literature dealing with the love that exists between men and women.

4. Sex and Society. Much of the structure of our modern society depends on our need of food and other comforts. Thus our farming and the transportation and distribution of crops is built up around the need of food; our stores, manufactures, banks, and the industrial system generally relate to food, the need of clothing, and the

other comforts of life. But beneath all of this and equally important with the other needs is the need of reproduction and mating. This is what makes the home as we have seen, and it is on the home and the family that our modern society rests.

The monogamous home, where one man and one woman live faithfully together and rear their children in sympathy and sacrifice, this is the cornerstone of the particular form of society that we know. No other forms of mating will give us the home as we know it, nor society as we have it. There are of course still many crude and wrong things about our homes and our society, for we are still selfish and animal in many ways, but we are sure that no other form of marriage would furnish so good a means of rearing children and of giving them a permanent home and a start in life—and this is the prime work of society. Possibly this little book has helped you appreciate how much of your own happiness and chance you owe to the principles we have studied. Surely then you will strive to do your full part to keep the stream of life clear and pure for your own sake and for those who are to come after.

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